April 2017

Rheometer Market Analysis

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Rheometer Market Analysis

A Major Qualifying Project

Submitted to the Faculty of the

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

April 27, 2017

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Abstract

The goal of this project is to provide recommendations for the commercialization of eccentric viscoelastic rheometry. The project team accomplished this task by conducting research into the current market by developing a set of interview questions to survey industry professionals. However, the data collected needed to be supplemented by a product comparison study in order to determine the feasibility of commercialization. These results allow us to reach conclusions on the potential market impact of this method and the potential barriers to entry.

1. Introduction

In the biomedical engineering industry, there is an increasing need to measure the viscoelastic properties of biological materials. When viscoelastic materials undergo deformation, they tend to exhibit varying levels of both viscous and elastic characteristics over time. One example of a viscoelastic material is honey because it is able to resist shearing and strain over time as stress is applied. Therefore, it is necessary to measure the changes in viscoelasticity to understand how biological materials can be used in the real world. With the constant development of new biological materials and methods, the accurate measurement of viscoelastic properties provides a better understanding of their application. A Rotational Rheometer can take accurate measurements of the sensitive variations in viscoelastic properties, and is the focus of this project.

Professor Heather A. Cirka and Professor Kristen L. Billiar patented (publication #US20140102180 A1, 2014 & 2016) a new rheometric technique for biological samples. This new technique called eccentric viscoelastic rheometry allows for more accurate measurements of subtle viscoelastic properties in smaller, uniform or anisotropic samples. Quantifying the viscoelastic characterizations of soft tissues biopsies and fibrous protein gels can help us understand the complex systems at work in tissue development, wound healing, disease progression, and cell-mediation of engineered tissues. Additionally, eccentric viscoelastic rheometry can help analyze the viscoelastic behaviors in newly formed tissues and protein gels that are often unstable and cannot be measured by standard rotational rheometry.

The purpose of this project is to provide recommendations for the commercialization of eccentric viscoelastic rheometry. Our comprehensive marketing strategy targets current users of rheometric technology and possibly identifies new users in the future. In order to develop a strategy, our group must assess the feasibility of the method in the current market and produce a comprehensive analysis of its practicality. The strategy includes an analysis of the different business model canvases generated, the current rheometers used in the market, and the associated risks of bringing EVR to market. Additionally, our project assesses the current strengths and weaknesses of the patent, while identifying similar patents and the threat they pose to is commercialization.

Ultimately, the goal of the project is to gather the necessary information to understand if there is a significant need for eccentric viscoelastic rheometry. Based on previous correspondence conducted during the initial stages of this project, we found a lack of awareness of the current market, its size and the potential for a rotational rheology product line. Hence, this project was born. By providing a commercialization strategy our team determines market size and potential, and recommend an optimal approach for bringing this method to market.

2. Background

2.1 History of the Rheometer

The word rheometer translates from Greek as a device for measuring flow. The origin of the device itself dates back to the 19th century. Early rheometers were devices that measured electrical currents but that term and practice was later replaced by the galvanometer. The next evolution of the term dealt with the measuring of fluids (especially blood) but as the medical field evolved and needed to diversify; its sampling techniques had to evolve too. Thus the term and practice of viscometer was born to directly relate to fluid measurement analysis. Current rheometers are almost as diverse as the substances and forces that they measure.

TA Instruments, a leading developer of rheometers, defines this device as one that "contains the material of interest in a geometric configuration, controls the environment around it, and applies and measures wide ranges of stress, strain, and strain rate." What this means is that the instrument itself must be adjusted to the specific material it is measuring. There are several different types of rheometers, however we concentrated our research on rotational or shear rheometers since our sponsor used a rotational rheometer with EVR

2.2 Types of Rheometers

The main category of rheometers our group is concerned with, rotational or shear rheometers rely on rotational motion to achieve a shearing effect. In order to achieve the shearing effect in a rheometer, one must apply a force to the sample through rotation or other movement (Barnes, 2005). The first method was introduced in 1888 by Maurice Couette and the second method was introduced in 1912 by George Searle (Barnes, 2005). Using the two methods of measurement rotational rheometers can be classified into four different categories. A simple dynamic shear rheometer, or DSR can be used to measure the characteristics of a wide range of materials under varying conditions of temperature, stress, and strain. Rotational cylinder rheometers have two cylinders, one inside the other where the inside rotates at a known speed for calculating shear stresses on a sample. A pipe or capillary rheometer runs liquid through a tube with set dimensions and flow rates to calculate the shear rate on the tube. Finally, the last type of rheometer, parallel-plate or cone and plate rheometers use rotating plates or a shallow cone and plate with liquid between them to measure the shearing forces on the sample.

A dynamic shear rheometer or DSR has remained one of the most commonly used rheometers commercially and in industrial labs. "The original DSR set new standards in asphalt testing technology offering precise and accurate unattended operation." (Cooper Technology)

Since 1993 rheometers have been used to characterize and understand the rheological properties of asphalt binders making them fundamental to forming the chemistry and predicting the performance of these materials (Eschbach, 1993). In general, dynamic shear rheometers offer greater ease of use and performance than most types of rheometers. DSR's can be designed and optimized so that they work with any specific material, making it a versatile option when it comes to rheological measurement.

Sometimes referred to as the "Couetter" rheometer, the rotational cylinder rheometer consists of two parallel plates curved to form coaxial cylinders (Eldrich, 1978). While the inside cylinder is stationary, the outside cylinder rotates at a set velocity with fluid between them. When the velocity of the cylinder is changed the shear rate of the fluid can then be determined from the change in consistency of the fluid (Gwidon, 2016). Such instruments have been widely used for obtaining rheological data on low-viscosity fluids. For example, rotating cylinder rheometers are used to measure the viscosity of motor oils at -18 degrees celsius in order to assess its performance in engines under European and North American conditions (Gwidon, 2016). Additionally, rotational cylinder rheometers were used to acquire the first quantitative measurements of raw rubber's rheological properties (Eldrich, 1978).

The third category of rheometers is the pipe or capillary rheometers. Capillary rheometers are one of the oldest methods for measuring the viscosity of fluids. During the 1920s and 1930s these types of rheometers were regularly used by the founders of modern rheology to quantify all kinds of complex fluids (Eldrich, 1978). Unlike most rotational rheometers, capillary rheometers are less suitable for fluids whose viscosities vary based on the applied stress or force (Gwidon, 2016). Since capillary rheometers are based on the principle that only a specific volume of liquid will flow at one time, the flow through the capillary must be laminar to accurately measure the time. Only by accurately measuring the time it takes for a specific volume of liquid to flow through the pipe will you get the kinematic viscosity for that fluid (Gwidon, 2016).

The last type of rotational rheometer, that Professor Cirka and Professor Billiar used with their new rheometric measurement technique, is a parallel-plate rheometer. Conceptually one of the simplest rheometers, the parallel-plate rheometer rotates one plate at a known velocity parallel to a fixed plate at a set distance. The rate at which the sample is being sheared can then be calculated when you divide the velocity of the moving plate by the distance between them (Elrich, p.245).

However the ideal scenario, where shear rates can be calculated so effortlessly, is not assumed when using most commercially-available instruments. Instead, most users of commercial rheometers pre-arrange their sample geometrically so that the resistance to rotation can be easily determined (Kaukler et al., p.1). This disconnect between the ideal and the real world happens because the shear rate is directly dependent on the specific radius from the center of torque. Therefore, the parallel-plate sensor system cannot be characterized by a single shear rate but by a range of shear rates from zero radius to the maximum radius of the plates (Schramm, p.58).

2.3. Rheological Measurement

For the purpose of this project, we concentrate on the parallel-plate rheometer type. When using this type of device, sample geometry measurement techniques fall into three basic categories. These are: cone & plate, parallel plate, and cup & bob.

The Cone & Plate method is often considered the ideal measuring system because it is easy to clean and can measure samples of a very small size and volume. In this method, a sample is placed on the lower plate and measured using relations to the Cone Angle and Cone diameter as shown in the following figure.

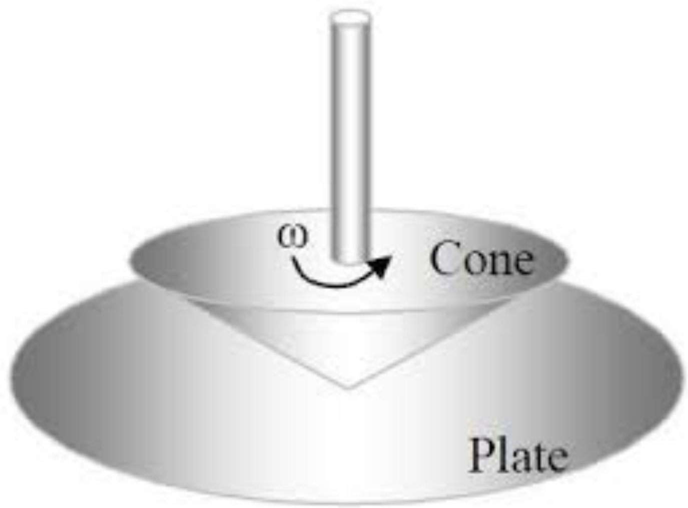

Figure 1 – A Cone & Plate measurement system

In this method, the sample should fill or expand to the cone diameter. A sample that is too small or "under-filled" cannot occupy the cone diameter and cause the top of the angle to overhang the sample and skew the data produced. A sample that exceeds the diameter or is "overfilled" would overlap the top plate and the extra material would not be analyzed properly.

Parallel Plates is the method where a sample is placed between two plates and then analyzed. These plates can either be the same size or the lower plate would be larger than the upper one. This method has the advantage of easily utilizing performed sample discs. It is important to measure samples with a known shear rate in order to obtain an accurate comparison since the shear rate can vary across the sample when using this method. Additionally, the nomenclature of the parallel plates is classified using the diameter of the upper plate. For example, a PP40 would be a 40mm diameter upper plate.

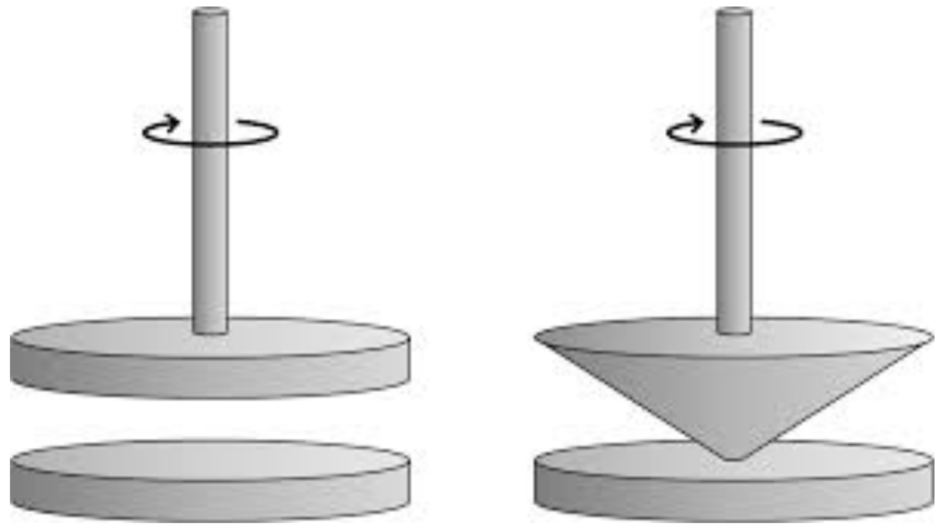

Figure 2 – Cone & Plate vs. Parallel Plate Measurement Systems

The Cup & Bob methods use devices of different shapes and sizes but are based on the same principles. According to our research, units that employ this method measure samples of a larger volume and are harder to clean.

Different rheometers use any one of these methods in order to complete their task of measuring samples.

2.4 Marketing Concepts

In the 1950's, Neil Borden outlined a marketing model called the "4 P's" which are Product, Price, Place & Promotion (Perreault, 1999 & 2010). This is also commonly referred to as the "marketing mix". Internal and external forces can impact any of these concepts and they interact with each other on a regular basis.

Product is defined as a good or service being offered by a company or group. The item or service should meet some sort of demand. In the case of innovating a current product, the new offering should appeal to those who have seen a need for the change in function/features. This allows a company to plan for every stage of the product's development and life cycle.

Price is defined as the cost of a product/service. In other words, how much would a consumer pay for this product? Payment could be physical money or some other form of figurative payment. Impacts on price would include a market's reaction to the product, competitive influences, cost of supplies, and the demographic that the product may appeal to.

Place is defined as how and where a product is sold. For example, you should only show a product/service to a market where individuals or groups exist who would utilize that product. Merchandising can have a major impact on Place. Many retailers place particular products in certain areas within their stores. Sometimes, it is an obvious place where every customer passes so this product is viewed by every patron. In this case, there is more chance of someone purchasing that product if more customers see it. In another case, a product could be marketed alongside a complementing product. For example, if one were to visit an electronics store to purchase a laptop, many times other accessories like mice, cables locks, cases, software are located nearby within sight. The customer would see these accessories and realize the need to purchase other items to make the laptop more useful. Thereby, the store would increase their revenue by merchandizing, or placing, other items to show mass appeal.

With the advent of the technological age, products and information are readily available on the internet. Companies can market to consumers by placing advertisements onto their favorite web sites.

Promotion is defined as any steps that are taken to bring goods and/or services into the limelight. Vehicles of promotion include advertising, public relations, and strategies. Promoting a product or service creates appeal. Just think back to the last major box office film that you watched. What kind of car was the hero/heroine driving? What type of cell phone did they use? Products and services used in that setting are displayed on a large scale and sometimes on a subconscious level to keep their brand in your mind so that the next time you are ready to make a purchase, you think of that brand first.

In our study, our group examines Price & Product by developing a set of interview questions to be posed to industry experts such as (but not limited to): representatives of existing companies who offer Rheometers on the market, other researchers and scientists with on hand experience using this device and in depth knowledge of how they work, salespersons in the medical device field. This allows us to determine what solutions/offerings are currently on the market and how a new or updated product would impact that market. We could uncover any new features that current users are looking for and if our sponsor's proposed changes would fill a market gap. We would be able to uncover any potential niches that would develop which would ultimately attract new buyers and developers.

The principle of Place (or Placement) is actually a vital component in the conception and production of this new technique/product. To stretch the definition of Place, we refer to the placement of the sample being analyzed (which is discussed more in the following sections). To relate Place within the Marketing realm, we can only use this principle in terms of geography. We have to acknowledge that Rheometers would sell in higher quantities to those areas of the country and the world for that matter where centers of influence exist in this field. The Commonwealth of Massachusetts is a renowned area for biomedical research and practice.

All of these concepts are useful as we analyze the potential market for a new type of measurement technique to enter the fold.

2.5 Make vs. Buy Decision Making Process

This process is defined as the evaluation that an organization must make when developing a product and/or service. The make decision would entail the organization developing the offering internally and the buy decision would entail outsourcing the development to another organization or outright purchasing the product/service from an organization. Organizations confront this analysis need when the market demands change and the organization must adapt to keep competitive and they must make a change in their current production structure. For example, a change or delay from current supplier(s) would propel an organization to reevaluate their current processes.

Benefits of the Make decision include lower production costs, full control over every stage of production, definitive management over the quality of the product.   In-house production is made with existing assets with no other overhead costs for design, production, fabrication, shipping, and other monetary expenses.

Benefits of the Buy decision include using other resources to complete the fabrication, usage of product and/or service that already exist. For example, if an organization has limited personnel and resources, then the Buy decision would make the most sense as the organization can rely on the personnel and resources of the outsourcing organization. Disadvantages of the Buy decision would be attempting to modify a company’s existing offering to fit the purchaser's need. In other words, would TA Instruments’ ARES-G2 model Rheometer work for an organization’s specific tissue analysis need?

Another disadvantage to the Buy decision is the market saturation of rheometer technologies, measurement techniques and models. Therefore, the multitude of options and features can overwhelm potential buyers.

Lastly, outsourcing would not allow the organization to keep their offering proprietary. It is understood that a company can protect its secrets with non-disclosure agreements and other legal measures but too many outside influences could lead to others reproducing the former company's offering ahead of intended market release.

Market conditions can impact an organization and start them down the path into this arena. New government regulations often impact the way companies can operate. In order to comply with potential new regulations, organizations would have to adapt their products/services. Then the organization would have to evaluate whether or not to adapt their offering internally or externally.

There are many models (graphical and conceptual) available regarding how one would arrive at the end decision of make or buy. We found the model from Cleverism's website (Martin, 2015) to be the most comprehensive.

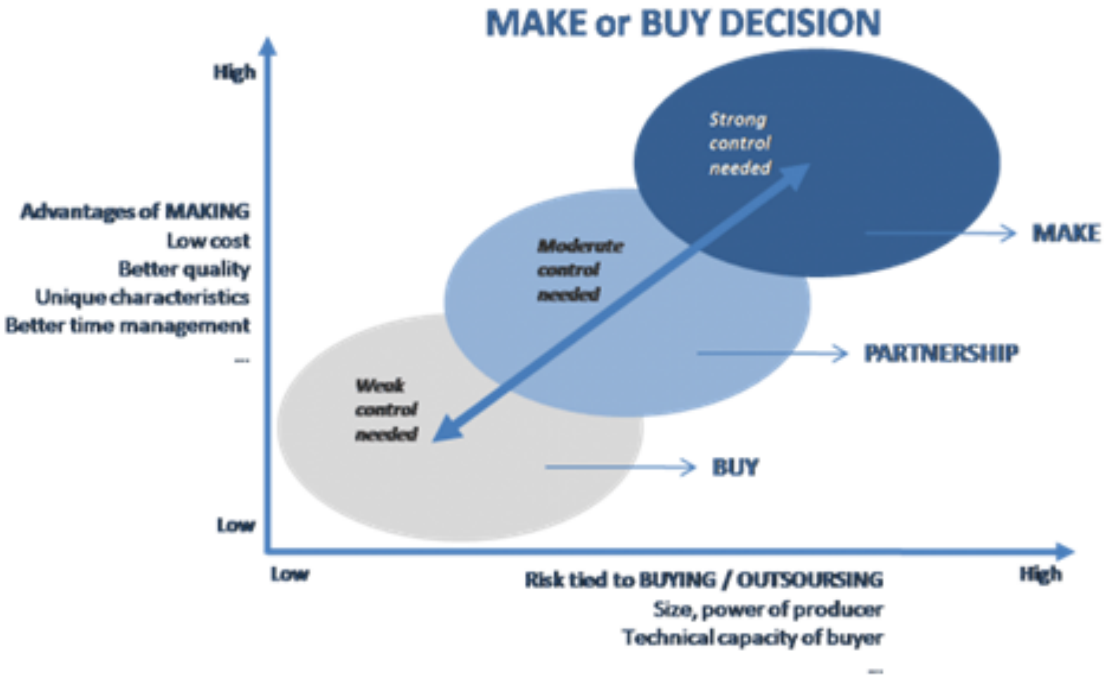

Figure 3 – Make or Buy Decision Matrix

In the real world case of our project sponsors, existing rheometers could not measure irregular shaped biological samples to a lower degree. Thus, the desire arose for their group to innovate current market offerings. They had to progress through this decision making process when first conceptualizing their innovation to current rheometer technology. Do we construct the new idea within labs on campus? Or do we farm out our idea and let another organization complete the task? They presumably arrived at the Make decision so they could have total supervision over the project throughout its development and not let their idea into the marketplace prematurely. Thus, they protected their idea and used the resources on hand to fabricate their end result.

2.6 Industry Competition

Currently, there are many companies in the marketplace who manufacture rheometers. Additionally, there are many types of rheometers on the market.

TA Instruments, with its headquarters in New Castle Delaware, is a major player in this arena (Sherman, 2004). Their customer feedback is available to the public and their customer base scores them with a 96.5% satisfaction rate. Their customers range from a wide variety of fields within industrial and university laboratories. They offer numerous models, a couple of which are the ARES-G2 and the Discovery HR series. The ARES-G2 rheometer measures stress and strain independently while the Discovery HR series is available in three hybrid models which differ based on levels of sensitivity and capability. For example, the Discovery HR-3 model is the most sensitive in that its sensors are “next generation” precise and many have patents pending. They do not differentiate the remaining models but state that a sales representative will configure the appropriate system to fit their customers’ needs. This company boasts that the ARES-G2 is “recognized by the rheological community as the industry standard to which all other rheometer measurements are compared for accuracy.” TA Instruments also offers many accessories that can change the configuration of the unit(s) and are easily swapped out. Each accessory would increase the unit’s function and would lead to a higher price. Their products meet the ISO 9001 standards.

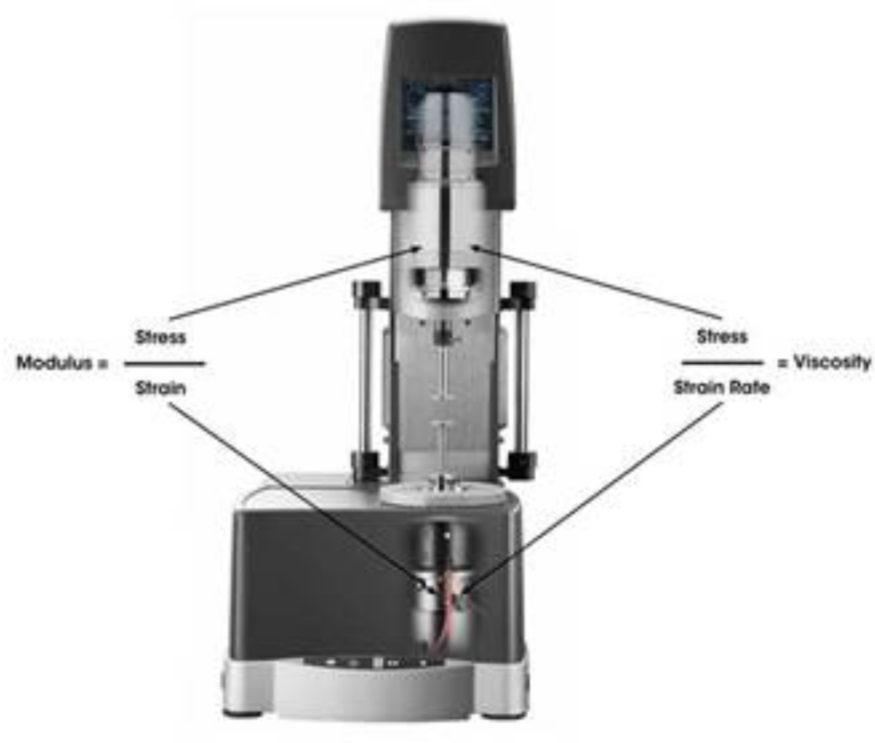

Figure 4 – The ARES series Rheometer

Anton Paar USA Inc. is another major player in this field. This domestic company is headquartered in Ashland, VA and the parent company Anton Paar is located overseas in Graz, Austria. They also have numerous subsidiaries all over the world. The company's rich history started when the company's namesake, Mr. Anton Paar, opened a machine repair business on his own in 1922. His work ethic helped him earn a strong reputation and allowed him to network with universities and research firms. From there, Anton Paar experienced consistent growth. In 1963, corporate leadership became Ulrich Santner's responsibility. He led the company into the measurement technology field and reinforced his company's relationships with universities and research firms. The company itself grew from 20 to about 130 employees. The next stage of Anton Paar's evolution arrived in1986 when Ulrich's son in law Friedrich Santner joined with the corporate leadership. Friedrich became CEO in 2002 and opened the company up to the world by establishing branches in other countries. He developed new sales and service subsidiaries and acquired similar companies who specialized in measurement technologies. During this tenure, the company's profits grew twenty-fold and the employee base grew from 130 to more than 2,200. They now manufacture a wide variety of analytical instruments which range from Carbon Dioxide meters and sensors, refractometers, sound velocity sensors, tribometers, and of course Rheometers.

They offer rheometer models such as MCR 702 TwinDrive and the MCR 72. The company highlights the former model as ground-breaking since it is the only rheometer of its kind to offer testing using two torque transducers and drive units that operate at the same time. The latter model is a compact unit that the company states is a wise choice for "quick and easy rheological measurements". The features state that it is easy to use due to its compact size, its Plug and Play capabilities and is available at an accommodating price. This model can also be ordered as an EDU package which is best for academic settings. This package grants a discount to academia and can be ordered once a semester for any number of registered students. The EDU package also comes with a textbook, USB drive that is loaded with study materials, and gift packet that contains branded promotional items.

Lastly, Thermo Fisher Scientific Inc. is yet another competitor in this jam packed market. This company is headquartered in Waltham, MA and was formed in 2006 by the merger of Thermo Electron and Fisher Scientific. Through a series of acquisitions, most notably Life Technologies Corp for $13.6 billion in April 2013, Thermo Fisher Scientific has become a powerhouse in the precision laboratory equipment market. According to company figures, 46% of its sales are in life sciences, 20% in healthcare, and 34% in industrial/environmental and safety which all roll up to revenues of $17 billion. They employ over 57,000 personnel.

They offer a rheometer model called the Haake Mars Rheometer. This model seamlessly connects to Thermo Fisher Scientific's other related medical devices xo that information can be shared across multiple platforms Additionally, accessories are available for specific applications. For example, polymers, petrochemical, pharmaceuticals, cosmetics, paints, inks, coatings, food, construction and building materials. The company's website advertises many promotional discounts presumably to attract website viewers to review them and attract new customers. A request for a quote for one such model went unanswered.

The remaining market share is portioned out amongst other companies around the world. We chose to highlight three of the more popular companies. Additionally, these companies are major players in this marketplace but do not solely specialize in rheometers alone.

Additionally, another field of study intersects with Rheology is that of Viscometry. According to www.dictionary .com, Viscosity is the property of a fluid that resists the force tending to cause the fluid to flow. Rheometers and viscometers differ from each other in minute ways. For example, a viscometer (also known as a viscosimeter) is an instrument used to measure the viscosity of the fluid and rheometers have more application potential in the complete analysis of a substance. Liquids with viscosities which vary with flow conditions are measured using a rheometer while viscometers only measure under one flow condition. Additionally, rheometers have a wider range of pertinent accessories and quality control applications.

The specific types of viscometers are the Falling Ball, Piston Drop, Oscillating Piston, Vibrating, Rotational, and Rotational-slit.

The Falling Ball viscometer was developed by Fritz Hoppler in 1932 and was the very first device to measure dynamic viscosity in the world. He also developed other types of these devices that are not widely used in current practice. According to Brookfield Engineering's website:

"The Höppler principle is used to measure the viscosity of Newtonian liquid by measuring the time required for a ball to fall under gravity through a sample-filled tube that is inclined at an angle. The average time of three tests is taken; the result is converted into a viscosity value using a simple formula." (http://www.brookfieldengineering.com/products/viscometers/laboratory-falling-ball.asp)

The Piston Drop method, or Norcross viscometer, which was named for its inventor, Austin Norcross, has two major components: a piston and a cylinder. An internal sensor is submerged into the fluid to be measured. During operation, the piston is lifted and the fluidic sample is placed in the void between the piston and cylinder wall, then the piston is released and falls by gravity. Measurements produced are a product of the time it takes for the piston to move through the fluid. (Beacon Industrial Group)

The oscillating piston viscometer (aka electromagnetic viscometer or EMV viscometer) was invented in 1986 at Cambridge Applied Systems in Boston, MA. The sensor (see Figure 5) contains a measurement chamber and magnetic piston. Measurements are recorded when a sample is first placed into the thermally controlled chamber where the piston resides. A controlled magnetic field oscillates the piston and this effect causes shear stress on the liquid or gas. The output results are determined by measuring the travel time of the piston. This is the viscosity. Other parameters like spacing of the sample between the measurement chamber and piston, strength of the magnetic field, and the travel distance of the piston can influence the results.

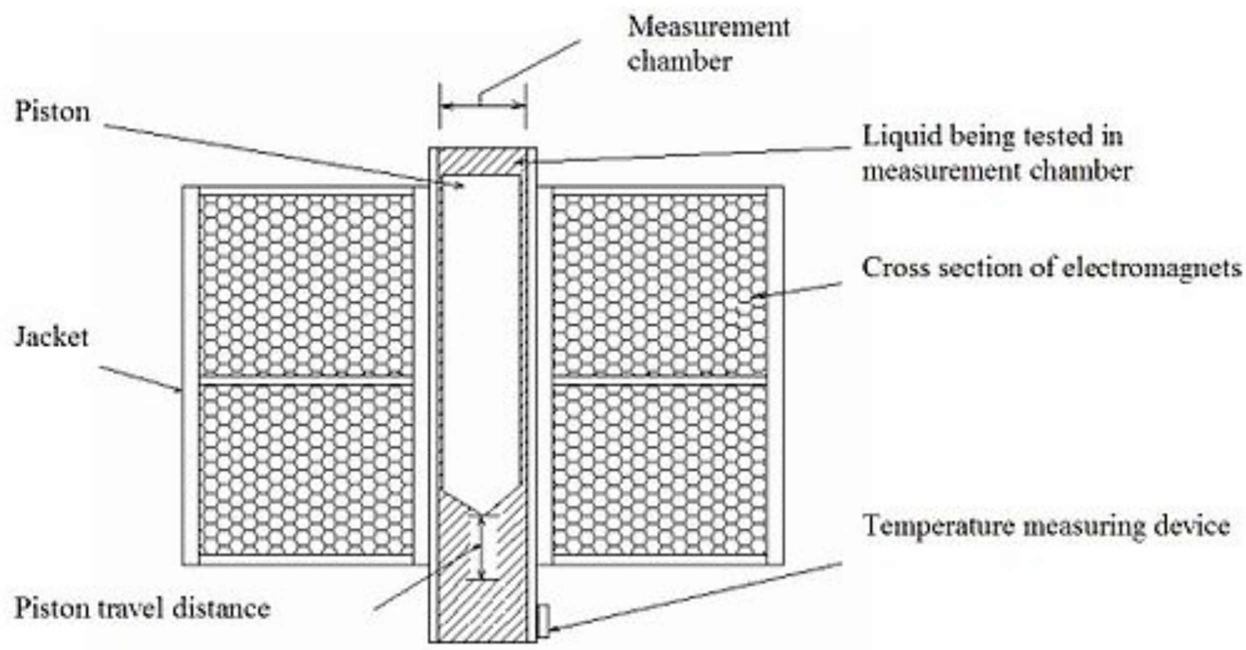

Figure 5 – A rendering of an Oscillating Piston Viscometer

Vibrating viscometers date back to a device called the Bendix instrument and was first seen in the 1950's. Vibrating viscometers measure the damping of an oscillating electromechanical resonator immersed in a fluid whose viscosity is to be determined.

The quartz viscometer is a distinct style of vibrational viscometer. In the case of this device, an oscillating quartz crystal is immersed into a fluid and the specific influence on the oscillating performance defines the viscosity.

Rotational viscometers act similar to rheometers in that they use “Cup and Bob” and “Cone and Plate” methods in order to measure samples. These methods were explained in a previous section.

The Rotational-slit viscometer was designed and developed by RheoSense, Inc of San Ramon, CA.

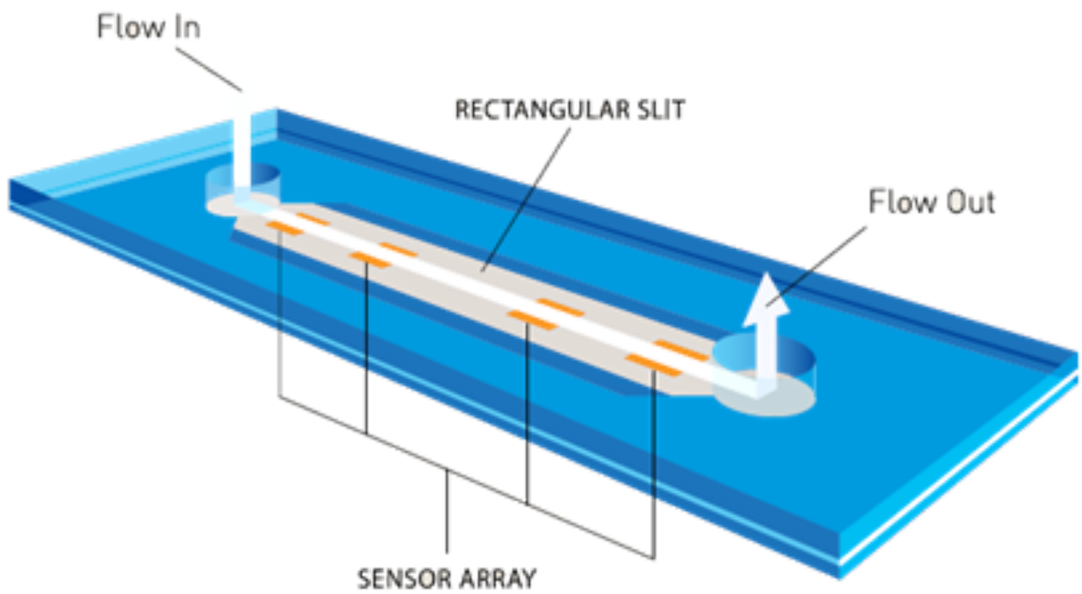

Figure 6 – Schematic of VROC® rectangular slit microfluidic cell

This device is operated by forcing a test liquid (ex. Glycerol) to stream through the flow channel at a constant rate. During this process, the pressure sensor array measures pressure as a function of position.

Additionally, RheoSense, Inc's website states, "VROC® powered viscometers allow complete characterization of viscosity as a function of shear rate or temperature" (http://www.rheosense.com/technology) and only requires a few micro-liters of fluid to perform measurements.

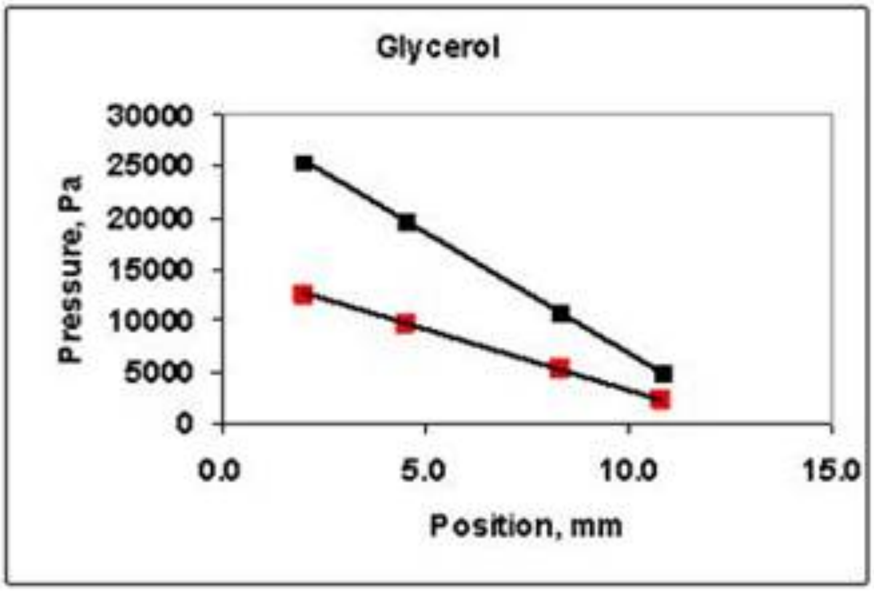

Figure 7 – Pressure as a function of position for low and high concentration glycerol samples (http://www.rheosense.com/technology, Figure 2)

Figure 7 shows an example of the raw measurement data for two glycerol samples. Higher glycerol content would result in higher viscosity and a larger pressure drop through the micro-channel (black squares). On the other hand, lower concentration would result in lower viscosity and thus, a smaller pressure drop (red squares).

A number of the companies previously highlighted also manufacture viscometers. For example, Anton Paar USA makes the SVM Stabinger Viscometer series models. This series offers three different options that each measure kinematic viscosity at different temperature ranges per model. This company also offers a number of add-on accessories to improve upon the original and would increase the price. Common applications of these models include petroleum and other fuels, power generation and cosmetic ingredients.

Brookfield Engineering carries two models of Falling Ball Viscometers. The KF30 has a fixed angle of 80 degrees and complies with a widely used industry standard of measurement in this device category (*DIN 53015*). The KF40 model has a wider array of angles: 50, 60, 70, and 80 degrees. Some of the applications of these models include analyzing beverages, paint, polymers and cosmetics.

2.7 Barriers to Industry Entry

Professor Billiar acknowledged that his group was not the first set of researchers to tinker and adapt rheometers to measure odd-shaped samples more efficiently. One marketing concept that applies here is "threat of substitutes" which occurs when groups within the same industry work on the same product or are producing the same end result (Porter, M., 2004).

However, they were the first to add certain components to observe these samples to develop constants. We believe that this fact would set their technique apart from the others within the market.

One addition that has been tested by this group is the use of camera equipment to study how samples behave in different testing parameters and positions. Previous to this innovation, most software would only display average values. This new evolution has allowed researchers to show constant patterns and develop solid and accurate data. These epiphanies have led us to ask "why is this technique not being more widely used? Are there price limitations? Does this technique somehow contaminate the results?"

Furthermore, will industry professionals accept this new technique? Our research delves into this very question. Innovative ideas are released into the medical device field on a constant basis. Researchers may be set on using their current preferred method of testing. It is up to our potential findings to show the value of this new technique so that industry professionals appreciate its impact on their own results.

The interview questions developed for this project endeavor to answer the question of how the market and industry professionals will view EVR. (see our Methodology section for more information)

2.8 Outperforming the Market

After this new product has entered the industry and their technology is accepted and utilized by others, they will need to build barriers to entry in order to protect their position. One of the great things about competitive markets is that other researchers and/or organizations seek to improve upon one's innovation. In order for Professor Billiar's technology to remain unique, he or his business partner(s) must make it difficult for others to enter the market.

There are three strategies to fend off other competitive sources by outperforming the market. They are:

1. Overall Cost Leadership
2. Differentiation
3. Focus

2.8.1 Cost Leadership Strategy

Cost Leadership does not simply mean offering their product at the lowest price. It also means trimming the operations and costs of the organization and/or team as well. Management should tighten the proverbial belt in order to control costs and develop an efficient operating plan. On the flip side, investing in operational cost of R&D and quality control, developing strong sales and service teams, advertising, and efficient facilities tactics allows our sponsor to stay ahead of the market. It is all about finding the balance.

2.8.2 Differentiation Strategy

Differentiation takes various forms in its application to keep a firm's product/service unique. The forms can include: brand image (or branding), technology, features, customer service, and dealer network. Branding is the exercise of creating a name, design or overall image. A noticeable brand would become recognizable to anyone with basic knowledge of the market. For example, Mercedes-Benz is top of mind when a person thinks about the luxury car industry. In order to stay ahead of your competitors, you must know who they are and/or what new researchers are working on that may be directly competitive in the near future. Technology and features are how the product works and how the company can keep its image fresh by keeping up with current trends and user-friendly options. Customer service and dealer networks show that it is important for a company to know their clients and business partners. Quality and speedy customer service that is integrated across business lines ensures that the company can retain and expand its client base. As an example, customers expect free shipping in today's market (Solomon, Micah; 2014). Amazon has created the brand standard by offering free shipping and thus differentiated themselves from other online retailers. Additionally, strong relationships with a company's supplier(s)ensure loyalty to your brand and potential price reduction arrangements through discounts, rebates, etc.

2.8.3 Focus Strategy

The focus strategy is a concentration on a particular demographic in order to market and sell your product. While the other strategies discussed encompass a wider range, the focus approach takes on many forms and is directed at one market segment. Thus by narrowing the spotlight, the firm can achieve more efficiency than their competitors who are acting more broadly. One great feature of the focus strategy is that it can be used to select targets that are least vulnerable to substitutes or where competition is not high.

One case study for the focus strategy highlights Porter Paint. This company focuses on professional painters rather than the do-it-yourself (DIY) market. Their tactics are built on free paint matching services, fast delivery turnaround for even smaller amounts of paint, and free coffee rooms at all of their factory stores that allow a break and refreshment to their busy professional clientele.

2.8.4 Stuck in the Middle

Figure 8 below illustrates the differences between Porter's three generic strategies: Cost Leadership, Differentiation, and Focus. A company that is "stuck in the middle" is one without a clear strategy position and has low market share, lacks capital and cannot compete with cost models and low profitability. These companies typically lose high volume customers who demand lower prices because they cannot compete due to tight profit margins.

Once a company is stuck in the middle, it would take a concentrated change in its corporate culture and time in order to remove itself and become a consistent force. In order to get out of this status, this type of company would have to assess its fundamental strategies and position itself to achieve or even buy market share (cost leadership), align to a specific pursuit (focus) or achieve some uniqueness (differentiation).

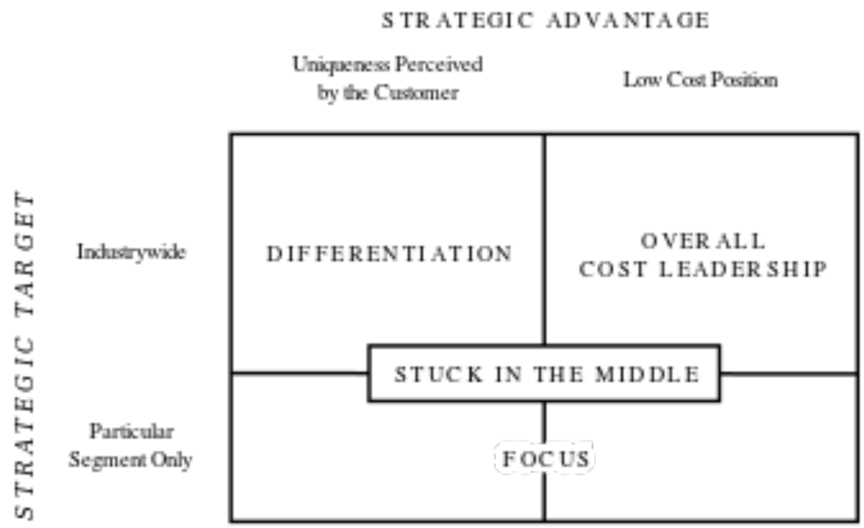

Figure 8 - Three Generic Strategies (M. Porter, 1998)

2.8.5 Strategy Risks

One source (Lister, J; 2017) states the risks to Cost Leadership are:

- Limitations of manufacturing processes
- Increasing business size
- Keeping workers motivated.

Technology is constantly evolving and companies must keep pace in order to compete. The first bullet comes into play when a company cannot "stay ahead of the curve" by internally updating inefficient or outdated technology. Additionally, the inability to raise capital to purchase this newer equipment and training the workforce to become aware of the updates and/or new features can lead to an organization falling behind a competitor that has a sharper concentration on technology and manufacturing processes.

A company must actively manage its growth and construct a plan for every stage of that growth so it does not outpace its current capacity. Uncontrollable growth in business size leads to unbalanced financial projections and dried up operating capital that will not sustain future operation.

A company's workforce must be a cohesive unit in order to achieve its goals. A benefit and/or recognition structure can keep employees invested in the business' success. "When you recognize people effectively, you reinforce, with your chosen means of recognition, the actions and behaviors you most want to see people repeat. Your recognition reinforces the employee's understanding of how you would like to see him or her contributing in the workplace." (Heathfield, S; 2017)

As buyers become more sophisticated, their need for differentiation can decrease. Thus, buyers can deal with sacrificing features and or services in order to obtain savings in a tight economy. Additionally, imitators can flood the market and try to copy the original and pass it off as their own.

Lastly, the focus strategy limits companies from grabbing more overall market share as there is only a finite number of companies in which to prospect. Additionally, competitors find effective ways to match an original firm's capabilities and the limited demand available within a niche can cause problems (Open textbook; 2016) in serving the firm's chosen, focused demographic.

2.9 The Commercialization Cycle

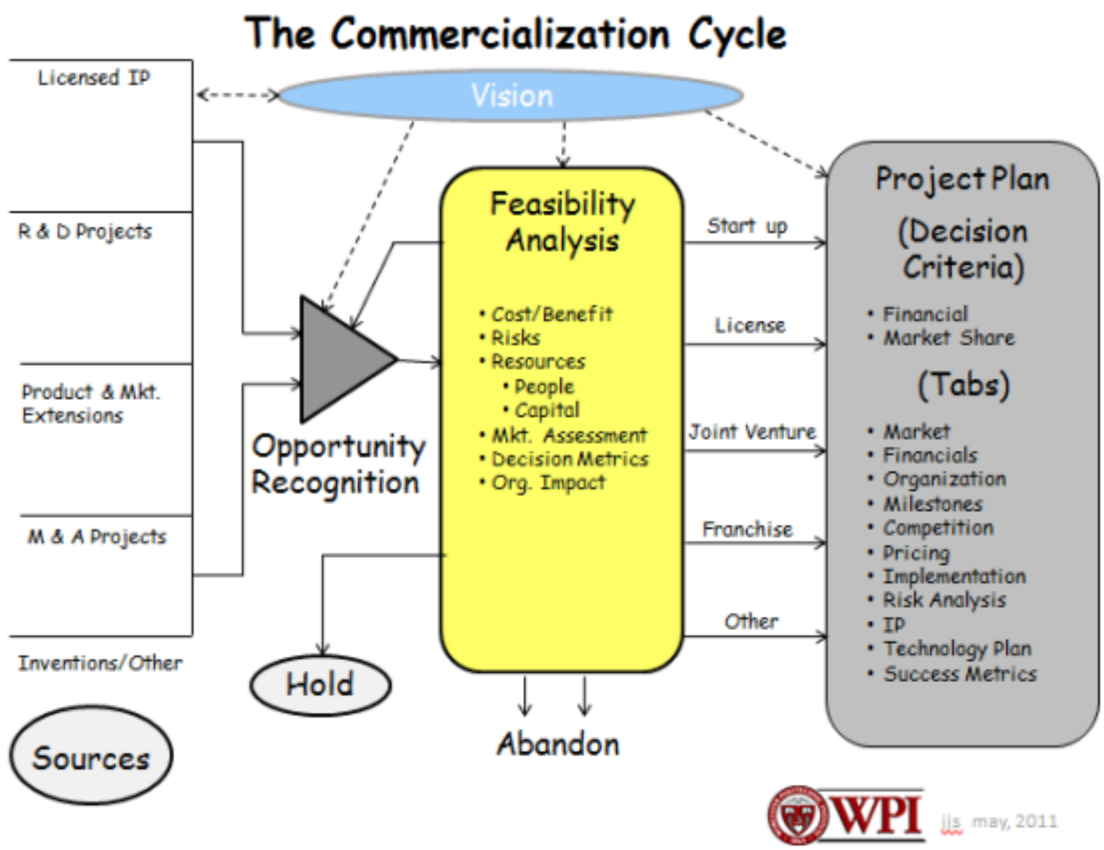

Figure 9 - The Commercialization Cycle (Schaufeld, 2015)

What this diagram above does is effectively map out the full commercialization cycle. In a general sense this map guides us through the process of first recognizing a viable opportunity, analyzing its feasibility, then determining how to get the product or idea to market through project planning. Once you are done with analyzing the feasibility of your opportunity there are many options and paths you can take. Holding on an opportunity can be a realistic commercial option because it gives the entity additional time to realize more value in its opportunity and workout how it can be commercially viable. Holding can also be a valuable asset when it comes to product commercialization because as society and people change a niche for your idea might open up in the near future.

Abandoning an idea or product could be the most difficult part of the commercialization cycle for a firm, especially if that opportunity seen is the reason you got into the business in the first place. However, the most important part of the commercialization strategy is understanding that opportunity recognition is a constant process that evolves over time. Realizing that one opportunity has no value and must be abandoned allows for the recognition of another opportunity.

The next step in the commercialization cycle only occurs if the company has determined that the opportunity is commercially viable in the current market. Making the choice of how to bring the idea to market by start-up, licensing, joint venture, franchising, etc. is determined directly from the feasibility analysis. What this means is that all of the commercialization options should be initially explored and their strengths and weaknesses assessed accurately. Only after you are finished with the assessment can you determine what would be better for your product. Commercialization decisions can also be very dependent on the current situation the firm or individual finds itself in. If there is no firm to begin with a start-up might be necessary. If you do not have the resources, time, or money for a start-up, a commercial license might be the better option.

Essentially, what the commercialization graphic above shows is that every stage in the process can be analyzed and should be analyzed from multiple perspectives. A comprehensive examination of each stage allows the company to make faster, more accurate decisions when it comes to new product development.

2.10 Business Model Canvas

One method for completing an effective commercialization analysis is creating a business model canvas. By creating a business model canvas for every option that your firm has you can simulate how each would play out and respond to changing conditions it faces in the real world. The other reason why the business model canvas is so effective is because it allows you to test models rapidly and often. Quick, rapid business model testing gives you the most up-to-date information on your models, keeps you prepared for emerging trends and opportunities, and allows you to adapt the model to changing customer needs. Being more responsive to changing conditions outside your model ultimately gives a product a more competitive edge in the market today. As a result, our group has created a business model canvas for each path to market that EVR can take, each of these models can be found in the appendix.

In order to fully analyze a prospective idea each of the sections in the business model must be filled out. In the customer segments all of the people in your organization that add value can be listed along with paying customers and simple users. For value proposition, the value created by each of your customer segments should be stated. Between customer segments and value proposition, the channels section should mention all the points at which you deliver value to your customers. The section above should describe the kinds of relationships you want to form with each of your customers through the proper channel. Below channels, revenue streams should make clear through which pricing mechanisms your business model is capturing value from each proposition.

On the other side of the business model canvas, key partnerships shows how many people can be leveraged to make the model work and what activities they need to perform. The next section, key activities should list all of the activities that you must be able to perform to keep your business running. Right below key activities, key resources describes the infrastructure used to create, deliver and capture value, this section also shows which assets are indispensable to your business model. Finally, at the bottom, the cost structure tells you what the costs are as they relate to the infrastructure of your business model.

The outside of the business model canvas should recognize and map the constraints that your opportunity faces in the real world. Each side of the model has different restraints that limit the sections of the model. The right side of the canvas contains segments that are currently growing and segments that customers resist. Above the canvas are key trends in the market, and regulations. The area above the canvas really represents how society is shifting as a whole and how that affects your model. Industry forces, dominant forces, competitors' weaknesses and disadvantages are all listed on the left hand side of the canvas business model. This side tells you how other businesses thrive or go out of business, also known as crowdedness and market volatility. Last but not least the bottom of your canvas outlines macroeconomic forces, global economic conditions, and risk in relation to the market, capital and infrastructure.

The CANVAS technique utilizes the bigger picture mentality by including multiple facets of consideration than other options that may concentrate on singular points of consideration (Blom & Vehof, 2012). Thus, we chose to utilize Canvas due to its customization and ease of viewing and comprehension. In other words, anyone can glance at it and understand its setup. Further, that person could understand why certain topics belong in the corresponding section on the model.

When researching other business models, we have learned business model types are constantly evolving and changing from industry to industry. However, in an analysis of business model cases, Michael Rappa and Paul Timmers have defined nine general types of models that exist in the business world; brokerage, advertising, infomediary, merchant, manufacturer, affiliate, community, subscription, and utility (Afuah, 2003). While all these models are designed for different industries and firms, they all share the same goal of making their business money in the long term. In order for a firm to keep making money in the long term it needs to provide customers some kind of value that their competitors cannot (Afuah, 2003).

3. Methodology

Since the ultimate goal of our project is to identify the value that can be created by eccentric viscoelastic rheometry (EVR), we must first develop a practical commercialization strategy. In order to accomplish our goal, an effective strategy meets the following objectives:

- Research
- Feasibility Analysis
- Recommendations

Research was necessary to first gain an accurate insight into the market for the method and device. Data gathered in our research came from biomedical industry experts, current users of the technology, and its manufacturers. By interviewing potential sources and conducting further background research in the industry we determined the feasibility of commercializing the device in the current market. Based on the previous analyses and possible decisions, our group provides recommendations for getting eccentric viscoelastic rheometry and its technology to market. The recommendations are in the form of a project plan for commercialization that have weighted decision criteria for financials, market share, organization, competition, pricing, implementation, risk analysis, IP, technology plan and success metrics.

3.1 Research

This section outlines the necessary steps for our research to identify the value that can be created by eccentric viscoelastic rheometry. The research includes initial background research on rheometry, and subsequent research on intellectual property, competition, commercialization, and the consumer.

3.1.1 Background Research

Our group first gathered background research on rheometry, the device and the current target market to perform a feasibility analysis. Background research provided a current picture of where rheometry technology is at the moment and its future outlook. Understanding the current state of this industry helped us assess if there was an immediate need for eccentric viscoelastic rheometry and its technology.

3.1.2 Intellectual Property

Further research on the current intellectual property in place and similar IP was needed to support our feasibility analysis. By gathering relevant information to the intellectual property of eccentric viscoelastic rheometry, we defined its target market and product potential. In order to gather the required information, we contacted Todd Keiller, the Director of Intellectual Property and Innovation here at WPI. By meeting with Todd and other intellectual property experts we found similar IP to assess the strengths and weaknesses of EVR's patent.

3.1.3 Competition

By gathering data on the competition that EVR faces in its target market, our group judged the difficulty of bringing its method and technology to market. It was necessary to interview experts in the medical industry and manufacturing companies to gain information on identical machines being developed and sold on the market. This research gives us valuable insight into the processes and material that goes into producing a rheometer, along with its associated costs and risks.

3.1.4 Commercialization

To understand how a commercialization strategy could be developed and implemented, we interviewed business experts in the medical industry. Interviewing these experts gave us a better understanding how to go about developing our own strategy for commercializing EVR. Furthermore, we evaluated these interviews if eccentric viscoelastic rheometry and its technology creates enough value in the current market for commercialization.

3.1.5 Consumer Research

The most important research method that we used collected data directly from the purchasing agents and true users of rheometry technology. Through a comprehensive survey, we obtained straightforward opinions of EVR, its technology and how practical it would be in the real world. However, before we sent out our survey, WPI requires Institutional Review Board (IRB) approval for data collection from human subjects. We went through the IRB approval procedure in order to survey the agents and users. The process involved filling out required paperwork and discussing the potential risks of collecting any data from human subjects directly.

We received an IRB exemption and proceeded with distributing our surveys to the desired target recipients.

3.2 Questionnaire Development

According to one source uncovered during our research, there are nine steps involved in the development of a questionnaire:

1. Decide the information required.
2. Define the target respondents.
3. Choose the method(s) of reaching your target respondents.
4. Decide on question content.
5. Develop the question wording.
6. Put questions into a meaningful order and format.
7. Check the length of the questionnaire.
8. Pre-test the questionnaire.
9. Develop the final survey form.

[Crawford, I M. (1997). *Marketing research and information systems*]

Our questions must be standardized to ensure that our data is trustworthy and testable. In other words, we should the same questions, in the same way, to every respondent in order to put the responses into a vehicle for testing and display.

Additionally, it helps if the questions are reviewed by a third party organization to ensure that no barriers are crossed. In this case, our questions were reviewed and approved by the IRB within the WPI Community for exemption from further review and we were allowed to send out our surveys to rheometer manufacturers and users.

Additionally, another source stated that you should ask the same question twice but in different ways. This ensures that your subject understands your topic and keeps them focused.

The research group must be able to pick out deviations within the data by incorporating this method.

3.3 Developing a Commercialization Strategy

When developing a commercialization strategy for eccentric viscoelastic rheometry, our group used the commercialization cycle to help visualize the process. Our process for creating a strategy included understanding the invention, recognizing the opportunities it creates, analyzing its feasibility, and building a business model from the feedback. Utilizing the same process, we constructed a business model for each path in the commercialization cycle that our opportunity could take.

3.3.1 Opportunity Recognition

The importance of recognizing and acting upon opportunities might be viewed as one of the most important, if not the most important, step in commercialization and developing a new business. As proposed by Figure 9, the commercialization cycle recognizes four sources of opportunity recognition; licensed IP, R&D Projects, Product & Mkt. Extensions, and M&A Projects. However, when defining opportunity recognition any source could be considered a potential opportunity if it has any economic value, newness, or perceived desirability for the product or service (Baron, pp.104-119). Therefore any product, service or idea that did not exist before, or has not been exploited and can generate profit could be seen as an opportunity. If this is the case, "opportunity recognition can, in turn, be defined as the cognitive process (or processes) through which individuals conclude that they have identified an opportunity." (Baron, p.107)

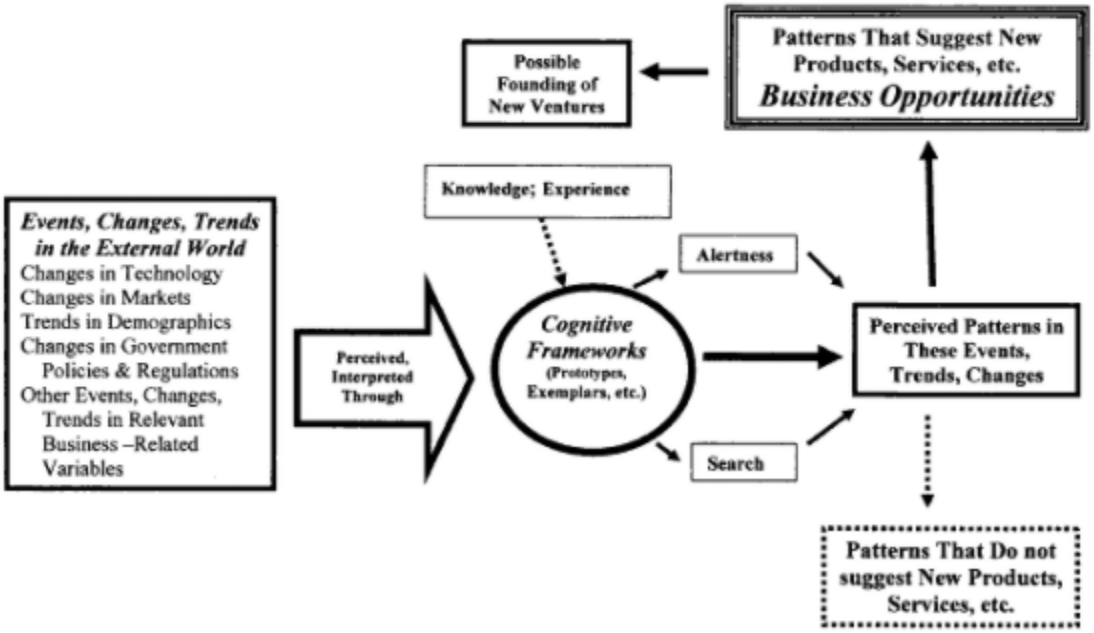

Figure 10 - Cognitive Processes for Opportunity Recognition

A large part of the cognitive process for identifying opportunities is recognizing patterns and trends in the current market and following the natural evolution of ideas. According to Robert A. Baron, when applying models of pattern recognition to opportunity recognition, two basic assumptions must be made,

> "Proposition 1: Opportunities emerge from a complex pattern of changing conditions- changes in technology, economic, political, social, and demographic conditions. They come into existence at a given point in time because of a juxtaposition or confluence of conditions which did not exist previously but is now present. " (Baron, pp.108)

For new rheometry techniques and devices, you can see how they have evolved and changed over the years. Currently, there is an increasing need to accurately measure a more diverse range of sensitive biological samples. Therefore, there is a need right now for a new rheometric technique like eccentric viscoelastic rheometry.

The second proposition that Baron mentions in applying pattern recognition to opportunity recognition is as follows, “Proposition 2: Recognition of opportunities depends, in part, on cognitive structures possessed by individuals-frameworks developed through their previous life experiences…” (Baron, pp.108). In this case, our past experience in business and engineering management helps perceive the previous connections made between eccentric viscoelastic rheometry and the new for new rheometric techniques in the commercial market.

3.3.2 Feasibility Analysis

Once we have gathered all the necessary information in our research, we use it to assess the feasibility of commercializing the eccentric viscoelastic rheometry method and technology. Using the commercialization cycle graphic in Figure 9, we evaluated each aspect in the feasibility analysis including costs/benefits, risks, resources, market assessment, decision metric, and organization impact.

In support of our feasibility analysis, we assessed its costs and benefits, intellectual property strength, target market potential, a decision metric, and other associated risks. A cost-benefit analysis showed the best approach to maximizing the utility of the method and technology while minimizing its costs. Defining the target market showed who purchases the device and how to reach them in the market. By completing a decision metric, we qualitatively ranked the possible decisions we made in the commercialization process. Finally, we analyzed the risks of each possible decision from both a qualitative and quantitative standpoint.

3.3.3 Project Plan

For the project planning phase of the commercialization cycle, our group used the decision criteria outlined in Figure 9 to build a business model for each path. In project planning, market and financial data was used to determine current market trends, volatility, and vulnerability for rheometry and rheometers. Market and financial data also helped find and identify the market forces that created the most value. One key factor in our model was understanding where disposable wealth accumulates, understanding this shows us which segments are growing, which are most desirable and which your customers resist the most and why. Analyzing current data on competition and pricing allowed us to see how competitive the market is right now for new rheometer technology, how resistant it is to change, and where would be the best opportunity for our method. A risk analysis of the target market identifies the possible dangers that exist right now if someone were to bring this new method to market. Finally, studying other similar Intellectual Property and building a success metric helped us develop the best possible recommendations for Professor Billiar and Professor Cirka.

3.4 Recommendations

Our group analyzed each aspect required for determining feasibility of EVR, we used the decision metric and chose the best approach. If the feasibility analysis shows that the value of EVR is worth pursuing then a thorough project plan is created. The feasibility analysis played a crucial role in our recommendation for Prof. Billiar and Prof. Cirka. Based on the direction that our analysis takes us, we recommend what type of organization the commercialization strategy forms around. For example, if we find that EVR is a viable business venture, but we lack the necessary resources for a start-up or franchise, it would be best to develop a strategy for licensing or creating a joint venture. However, if our feasibility analysis shows that EVR is not a viable business opportunity it might be better to recommend that the project be abandoned or held off till a more opportune time. Regardless of the final outcome, our group provides sound business advice for the further development of this new rheometric measurement method and technology. At the end of this project, our group must provide Professor Billiar and Professor Cirka with a final report outlining the research, analysis, and recommendations we have come up with throughout the project.

4. Results

Our project team distributed two different surveys in order to understand the two major influencers of the rheometer market: the users and the manufacturers.

Through online research and database queries, we developed a target list of manufacturers and users. We also researched scientific papers and patent applications that dealt with rheometers, along with academic publications that included research conducted using rheometers within the WPI database. We collected contact info for these patent applicants and authors/researchers and added them to our target list. After exhausting these search options, we turned to social media outlets to uncover even more contacts. Social media outlets such as LinkedIn provided us with the opportunity to search for individuals who worked for companies and organizations that manufactured and/or worked with rheometers. Through these means, we were enabled to send surveys to individuals rather than sending them to general inboxes where a survey could have either sat for some time before being forwarded to the appropriate person(s) or could have potentially gone unanswered.

Our target lists became cross linked since we found that some individuals who work for rheometer manufacturers were also named under the list of those we found who had used a rheometer. For example, Mr. Smith is a scientist who works for ACME Rheometers in a department that fabricates these devices. In scouring academic publications, Mr. Smith was found to have used a rheometer to conduct a study. In cases such as these, we added contacts like Mr. Smith to both survey requests.

Overall, through using the aforementioned methods, we distributed 203 surveys.

4.1 Survey for Rheometer Manufacturers

Our first survey was directed at manufacturers of rheometers to understand the trends of innovation and also the current products on the market. Our sponsors determined that our data collection would be more valuable to them if it afforded them cost information on specific real world models. Therefore, we tailored a couple survey questions to specific companies and their advertised models. One company, by way of illustration, may then have been sent a few variations of survey one, dependent upon how many models they offered, with two questions that differed slightly in direct correlation with the rheometers they manufactured. In the case of the companies we analyzed in our Background section, we chose specific rheometer models made by that manufacturer to focus on: the most common model, hereafter referred to as the "base model," and models with added features.

The outcome of our manufacturer survey efforts would allow us to analyze market offerings in order to determine a niche for our sponsors' innovations that would differ from current models and make a solid impact on the rheometer market. Through the responses garnered, we would be able to gauge and extrapolate how manufacturers currently meet consumer demand and what adaptations need to be made.

Please see Appendix A in order to view the full survey.

Questions 1 & 2 were changed, as previously outlined, to address specific models that certain manufactures highlight on their websites and other sales outlets. We asked these questions in order to determine cost vs. sales price. Through these answers, we could show our sponsors that current companies operate within particular margins when producing and offering their products and services to the marketplace.

Question 3 asked the potential respondents an open-ended question on product features. We were looking for their input and perspective on how product features are tailored to their customer base needs. We wanted direct input from the manufacturers here and did not want to offer any response options that could potentially compartmentalize (or compromise the validity) of this particular inquiry. In other words, if we provided response options, then the responses would be limited to those options provided. We felt this area of study required original thought and input directly from the source.

Question 4's purpose was to ask what factors influence pricing of the specified models. The answer format was "check all that apply." Therefore, we could collect data on numerous topics and narrow down commonalities using the questions that followed. Responses that the survey taker could choose from were:

a. Customization
b. Competition within Marketplace
c. Market Demand
d. Features
e. Manufacturing/Production Costs
f. Overhead Costs
g. Repeat Customer Relationship
h. Package Pricing (i.e. bulk pricing or discounts for customers purchasing more than one unit at a time)
i. Government Regulations

j. Other ___________________

Points g and h were geared towards determining if the company offered any discounts and/or rebates to their customer base. If so, we could extrapolate that the manufacturer in question is selling their product above the cost of development. Therefore, a profit margin would exist and discounts would allow the company to still earn income despite the decreased revenue. The answers would help our sponsors correctly price their own upgraded component and they could initiate their pricing process equipped with the knowledge of starting points for cost/benefit analysis before and after offering discounted prices. This information would give our sponsors a competitive advantage.

Questions 5 & 6 dealt with how the manufacturers prospected for customers. The results would tell our sponsors where other companies concentrate their prospecting efforts. Furthermore, they would be able to determine the most effective marketing tools to utilize, and the venues in which to concentrate their efforts. Both questions followed the "check all that apply" method. We felt this method was sound since a manufacturer could prospect using multiple mediums. For example, ACME Rheometers could send out email blasts and simultaneously advertise on social media sites, or employ any other combination of marketing tools. The same rationale was applied to demographics listed in question 6. ACME Rheometers could prospect to any combination of or even to all potential sources in order to "cast a wide net" and attract more buyers from more sources.

Questions 7 & 8 were posed to uncover how rheometer manufacturers actually fabricate and assemble their products. We chose to include the most common techniques found through the results of our research on the survey.

Please see Appendix A in order to view the full survey.

4.2 Survey for Rheometer Users

The second survey was focused on the user's experience and needs. By sharing the results with our sponsors, they would be able to determine if their innovation would appeal to the market and succeed with easy industry entry. Furthermore, this effort would reinforce our recommendations. The responses would also give our sponsors a clear vision as to whether or not this newly adapted technology would take a firm foothold in the market and plausibly become an industry standard.

Please note that these responses represent the opinions of those who replied to our surveys. Due to the small sample size of 2 responses (out of 203 user surveys sent out), we can only speculate and cannot generalize the results to account for trends or patterns of use amongst a larger population.

Questions 1 & 2 were constructed to establish how users employ rheometers. We wanted to establish a baseline to ensure our data set was accurate. From there, we could narrow down similar processes and similar analyzed materials to further filter the data and apply it to our recommendations. For example, if a particular respondent stated that they use a process not generally utilized or beyond normal industry convention, then we could omit that particular response in order to not skew our data. We also wanted to ensure that the process matched the analyzed material to ensure data integrity. Respondent #1: "Measure properties of asphalt binders" versus respondent #2: "we use it to measure straight viscosity, G" G characteristics include those of fluids and waxes." The commonality between both responses was that both respondents commented that they use a rheometer for typical research purposes—one for measuring asphalt binders and the other for measuring paraffin waxes.

Question 3 was aimed at uncovering if any users have found examples where their current measurement technique was deficient. We wanted to explore what specific steps they took to obtain their measurement objective(s). We asked the respondent to expand upon the yes/no type initial question. We could use this information to directly ascertain if our sponsors' innovative approach could potentially solve our respondent's issue. This question was key to discovering a niche and whether or not the survey taker could recognize that need in their current rheometer usage. The responses to this question were a 50/50 split. The respondent who answered yes to the previous question stated that he needed to use an alternative form of measurement to complete his goal of sample analysis.

Question 4 asked the respondents to consider potential improvements to their current product's accuracy. This question could help the customer, through realizing the need for modifications to be made, be more open to pitches for a new, upgraded unit. One respondent stated "Could be easier to use with different samples." The other respondent made a thought-provoking point: "I think accuracy is often affected more by loading technique than the instrument itself." We explored this supposition with our sponsor to determine the validity of the response and potential improvements to the current loading techniques available.

Question 5 is similar in nature to the previous question in that we intentionally left it open-ended to benchmark our respondents' original thoughts. We could then use these responses to see if any survey-takers were interested in our sponsor's technology without knowing about its existence. Again, both respondents had different answers: "More sensitive measurements, sturdier materials" versus "if a rheometer could double as both an extensional and shear rheometer that would be useful." The second respondent shows the intuitive thought process that our sponsors are looking for within the market because he is thinking of other innovations to conventional techniques.

Question 6 asked “Who in your organization would make the decision(s) on whether or not to make a switch of this nature?” Potential answers could be a person, company title, or department within an organization. For example, John Smith or the Director of Research, or the Finance Department could be typical responses. This information would be useful to our sponsor since this person or group would be the decision maker for an entire organization – the specific entities our sponsors would have to convince and win over during any potential sales pitch. Our sponsors could also directly market to this group. For example, if we found that the answers reviewed all pointed at one role or department, then the sponsors could use that information when targeting other, similar organizations. In our real world pursuit, we received ambiguous responses.

Questions 7 & 8 had predetermined answers so we could narrow down customer desires, so that our sponsors could tailor their offering once market-ready. Survey takers were only allowed to choose one answer for each question. In question 7, the targets were allowed to choose from the following options: Cost, Accuracy, Usefulness, Ease of Use or Versatility or Other. Question 8 allowed the users to choose Lower Cost, More Accurate Readings, Improved Usefulness, Easier to Use than Current Model, More Versatility than Other Model and Other. For both questions, it could be determined that if a user chose “Cost,” then in order for our sponsor’s offering to be attractive to these potential customers, they would have to ensure that they priced it low. One respondent followed a pattern in which “versatility” was his answer topic on both questions.

Question 9 was asked to gauge who made the final purchasing decisions within the respondent's organization. This would give our sponsors potential contact information or at least the proper departments to contact in typical organizations. For example, if 10 respondents who work for ACME Rheometry answered the survey and responded to question 9 with "the Purchasing Department" then our sponsors can contact the Purchasing Department within ACME Rheometry if they marketed their innovation to this type of organization. This data would give them advance information in order to be well informed.

Please see Appendix B in order to view the full survey.

4.3 Product Comparative Study

The goal of this supplemental section is to fill in gaps left by the survey results. In our product comparative study we compare and contrast current rheometer specification with the methods of eccentric viscoelastic rheometry. By examining what the market for rheometry is at the moment, we can determine if EVR's ability to extend the utility of standard rotational rheometers would be competitive or not. If we decide that EVR has value and a place in the current market, our job is to find out where that is and how to get it there. On the other hand, if EVR has no value in today's rheometry market, our objective is to explain how could be created and where to go from there.

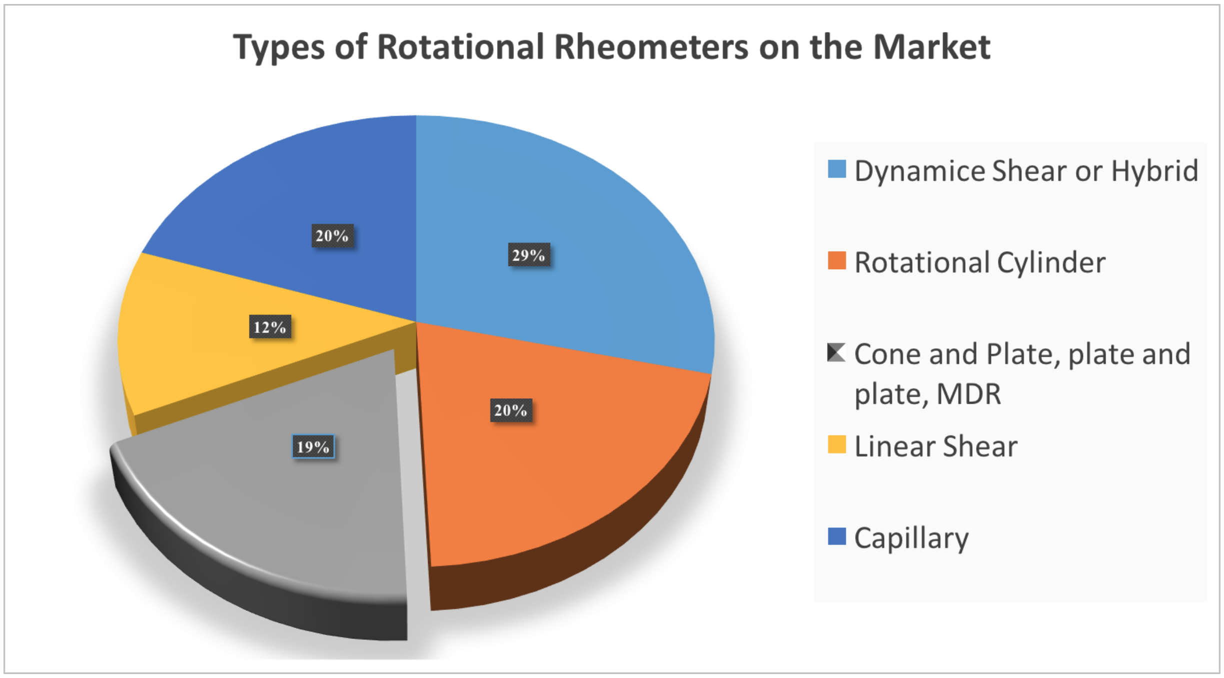

Figure 11 - Types of Rotational Rheometers on the Market

We started by analyzing the current market for rheometers. We collected data on forty manufacturers and distributors of rheometers with 136 different models. Our research as displayed in Figure 11, showed that the dynamic shear and hybrid rheometer design was the most popular, making up a third of the market. The DSR and hybrid was then followed by capillary and rotational cylinder rheometers, each making up 20% of the total market. Finally, plate and plate type rheometers made up 19% of the total rotational rheometers offered and linear shear rheometers made up 12%. Figure 11 also supports the idea that hybrids and DSRs are becoming more popular in the market because the leading manufacturers are only producing those types of units.. The movement to DSRs and hybrids was also reinforced by our background research. DSRs and hybrids have become the most popularly used commercial rheometer on the market because they are the most versatile and easy to use.

The strongest competition in the market comes from the larger manufacturers and distributors of rheometers. The competition includes companies like Anton Paar, Brookfield Engineering, TA Instruments, Malvern Instruments, Cannon Instruments, and Rheosense Inc.

According to Figure 12 below, these companies have the largest presence in the market because they are able to offer the widest range of rheometers. On average these companies offer up to several different models of each type. All of these models have many distinct features that are important for enabling scientific research, this includes:

1. Type
2. Size
3. Application
4. Speed Range
5. Frequency Range
6. Viscosity Range
7. Temperature Control
8. Pressure Control
9. Ruggedness
10. User Friendliness

When analyzing the feasibility of EVR, we must gauge the strength of the market by comparing models from the strongest competitors across the features listed above. Our group was be able to determine the dollar value of EVR on the market and how well it would perform against the competition based on this product comparison study.

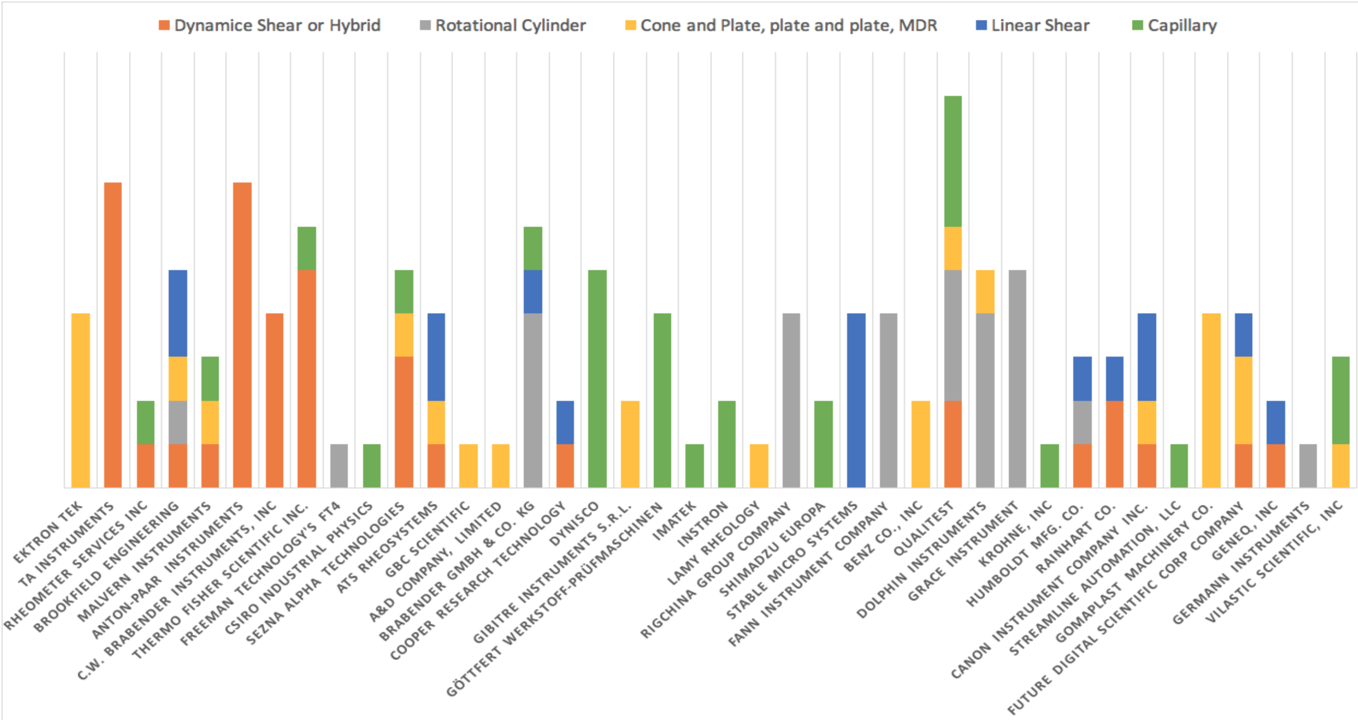

Figure 12 - Types of Rheometers Sold by Company

When analyzing types of rheometers on the market it is important to look at the variety that each company is able to offer. If a company only offers one type of rheometer with multiple models they can only be competitive in that one area of the market. Two of the main competitors in the market, TA Instruments and Anton-Paar Instruments, offer a diverse range of hybrid and dynamic shear type rheometers. Both companies sell attachments and accessories for their hybrid rheometers that allow the user to change their rheometer type instantly to match sample type and test. TA Instruments' rheometers come with Smart SWAP geometries that automatically adapts the necessary parameters to type, dimensions, and the material being tested (TA Instruments). Anton-Paar rheometers also come with a similar patented technology that automatically adapts to the type of measurement being done, the material dimensions and the environment (Anton-Paar). The use of hybrids and their ability to adapt to the type of measurement has made Anton-Parr and TA Instruments strong competitors in the rheometry market.

Size is also another important factor when analyzing rheometers on the market today. The larger the rheometer is the larger the sample you can test if you are testing materials such as asphalt or concrete. In general, the smaller your rheometer is, the smaller the sample you want to test. Although, size does not always mean that the rheometer will be better at quantifying larger or smaller objects. Most companies that we were able to research on the market had a range of rheometer sizes. All of the major competitors offer rheometers that are desk-sized, or stand on their own for use in laboratories under normal research conditions. On the other hand, Brookfield Engineering manufactures the RS Portable Rheometer, its portable size and dual power operation allows it to go directly from the production floor to the field for research (Brookfield Engineering). With the same features and specifications as the standard dynamic, rotational rheometer, Brookfield Engineering stands out among the other manufacturers and distributors.

The next, if not most important, feature to consider among rheometer models is application. The application of rheometry normally dependent on what you are measuring and why you are measuring it. Fundamentally, in terms of the "why", researchers use rheometers for three specific reasons: quality control, process optimization, and product development. However, in terms of the "what", "The list of materials for which rheometry is key is endless," says Bob McGregor, a Sales and Marketing Manager at Brookfield Engineering, "Everything that you can think of that is a liquid or a semisolid is probably being tested for viscosity." (Perkel, 2011) Since "everything" and "endless" are difficult concepts to grasp, our group put together the following figure in order to convey the applications of rheometers for types of sample materials.

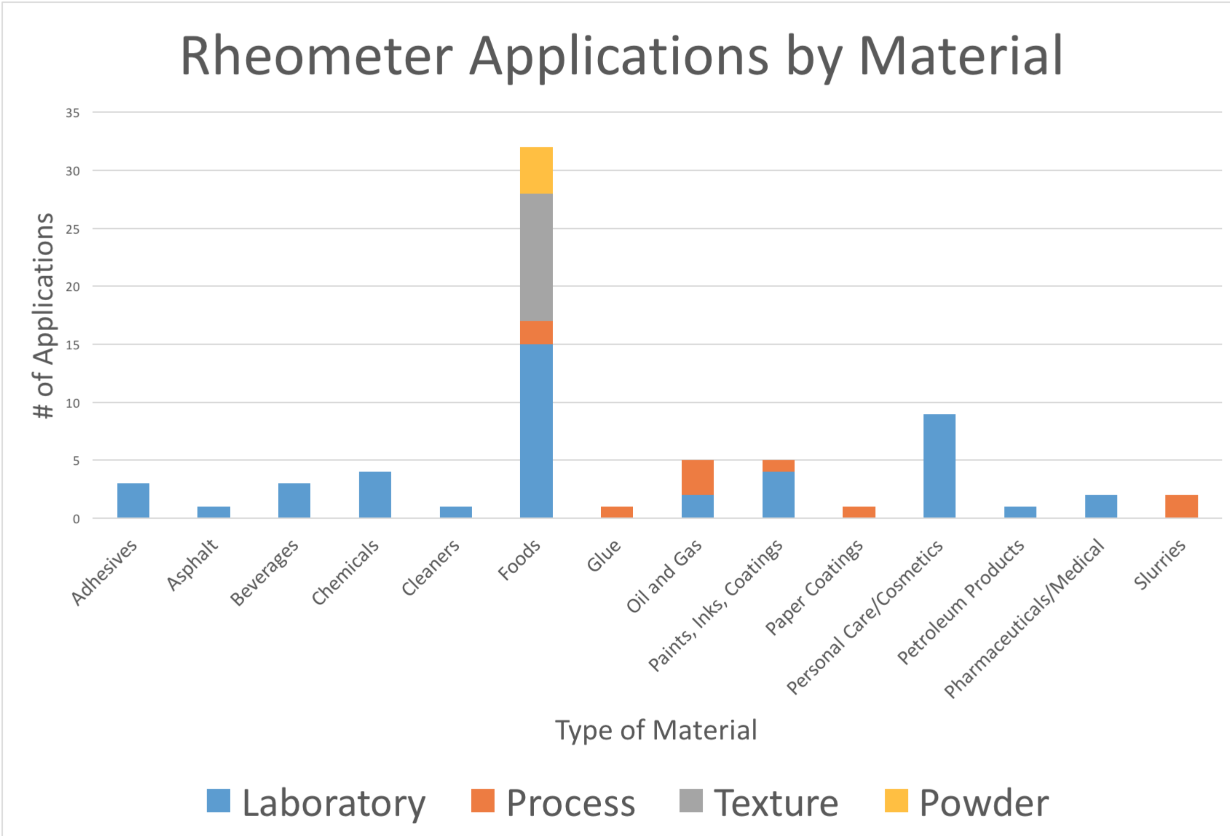

Figure 13 -- Rheometer Applications by Material

According to Figure 13, which was taken from a study conducted by Brookfield Engineering, the most applications for rheometry are in the food industry and the personal care/cosmetics industry. The food industry alone has the widest range of applications from laboratory, processing, texture, and powder applications in using a rheometer. Therefore, the greatest extent of growth in rheometer technology and technique is in that industry. All other areas of application share the same minimal range within laboratory and processing applications. The least amount of applications fall within the asphalt, cleaners, adhesive, paper, and petroleum industries. Pharmaceutical and medical applications of rheometry falls right in above the industries that share the least number of applications. What this data shows is that there is room for further development of pharmaceutical and medical applications, but the trend does not show a need for it at the moment.

For speed, frequency, and viscosity ranges, all of the major competitors in the rheometry market offer approximately the same amounts of accuracy and control. These three ranges can each be measured in their own specific way, speed and frequency range can be measured in rotations per minute or rad/s, and viscosity range is measured in units of viscosity called a poiseuille. Each company is able to provide a wide selection of products to measure any range of speed, frequency or viscosity that could occur in a lab. Across the specifications this shows that rheometer technology in general has reached a plateau where it can not move forward without a major breakthrough or having it cost ten times what it normally cost. The same seems to go for environmental control over temperature and pressure in the rheometers. Again, all of the models from each major competitive have the same temperature and pressure ranges listed in the specs and no significant company or model stands out from its competitors.

Ruggedness can be a difficult factor to calculate because most of specifications did not have a rating or description for ruggedness. However, when examining the designs and pictures of rheometer models for each of the competitors, all of the rheometers and accessories are made from precision machined metals and high density grade plastics. The addition of these materials makes them durable and resistant to even the most severe laboratory conditions.

User-friendliness can also be another important factor when comparing rheometer models. According to the Rheology Product Manager at TA Instruments, Russel Ulbrich, "rheometers are basically higher-priced tools that are able to measure not just viscosity, but materials elasticity and structure as well. With them, researchers can replicate in the lab the stresses and strains imparted during manufacturing and customer use, thereby facilitating product design" (Perkel, 2011). That works well for the scientists or researchers in the lab with years of experience working on complex instruments. However, people like Steve Carrington, the

Rheology Marketing Manager at Malvern Instruments, believe that the rheometers should also be made for the average person. The rotational Kinexus rheometer tries to accomplish this by offering a user-friendly approach to rheometry that does not require a deeper technical understanding to set the desired parameters (Perkel, 2011). Companies such as Malvern Instruments, TA Instruments, and Anton-Paar try to focus on making rheometric measurements as easy as possible for the user while providing a state-of-art technology.

5. Conclusions

5.1 Canvas Business Model Analysis

In order to analyze how a canvas business model of EVR would function in the real world we generated a model for each scenario in getting it to market. Our group developed a start-up, licensing, joint venture, holding, and abandon business model while still using the same model developed by Schaufield displayed in Figure 9. Our conclusions determines the success and failure of each model based on constraints, key trends, regulations, competitive forces, and other economic forces in the market. The following sections outlines our conclusions in further detail.

5.1.1 Start-Up Business Model

The largest, most important constraints on our start-up business model canvas are the lack of necessary resources, funding, and personnel for producing a product. Based on this disadvantage, the business is slow to get off the ground. With the available resources right now, including laboratory time, equipment, and staff, it would take years to get a final product approved for sale. In terms of funding, the further support of WPI is always in the question.

Since EVR is still in its early stages, the WPI Office of Intellectual Property & Innovation takes another year to evaluate the technology and market for potential licensee feedback. Of the 30 patent licenses signed since 2012, only 12 have become start-ups. The success of the 12 start-ups has been promising due to the WPI Accelerator Fund and its support of new business ventures. Investments from the fund of up to $50,000 have allowed these start-ups to function effectively and efficiently with very little overhead and few employees. The existence of the WPI Accelerator Fund makes a start-up business model canvas much more attractive because of the benefits and connections it provides.

Key trends in the rheometer market include an increase in the use and manufacture of hybrid rheometers, a focus in rheometric application in food processing, a plateau in rheometer technology, and a movement toward user-friendly rheometers for the average person. Based on our start-up business model Canvas, the increase in hybrid use is undesirable to model because EVR is only compatible with a plate on plate system. For our model, a focus in the food industry means less competition and application development in medical/pharmaceutical applications. This is positive for EVR because there is less competition in the medical industry and more room for improvement in the technology. When also considering the plateau in rheometer technology, any significant improvement, like EVR, could make a substantial impact in the medical market. In addition, the start-up model for EVR is not supported by the movement toward more user-friendly rheometers because it requires more knowledge from the user to operate.

Ultimately, there are already strong competitive forces in the rheometry market. A majority of these manufacturers offer a wide range of rheometer types that are designed to fit every application and need. For any start-up business model canvas entering this market there is a high probability that EVR is crowded out of the market or bought off because the barriers to entry are so high. In conclusion, a single start-up business model canvas, with a single rheometer and method of rheometry, is not able to compete against the industry giants that already rule the market.

5.1.2 Licensing Business Model

The biggest constraints on our licensing business model canvas are a lack of maturity in the market and patent litigation. Based on these disadvantages, it takes more time to determine exactly how much the patent for EVR could be licensed for. First of all, the market for a single method of rheology in the medical industry is immature and untested. The lack of maturity makes it difficult to determine exactly how much EVR would be worth in the market, however this uncertainty can also be beneficial for EVR’s value. If a target company sees the potential of EVR to analyze tissue and biological samples that other rheometers cannot, they might pay anywhere up to $100,000, if not more. On the other hand, if a company believes that the market is not ready for EVR or that the demand is not great enough, the patent could only be worth $10,000 or less. Furthermore, patent litigation can be an extensive process, since both sides have to agree on a patent value first before the deal is made. Unfortunately, patent litigation weakens the strength of our business model canvas for licensing EVR on the market.

Unfortunately, key trends in the market right now do not support the licensing of EVR in our business model canvas. An increase in the overall use of hybrid rheometers means that a company would have to take more time to adapt EVR into their technology, they might view it as more expensive or a waste of time. On top of that, the scarcity of applications currently in the medical industry, plateau in rheometer technology, and movement towards less complicated machines all makes EVR less attractive to established companies in the market. Due to the current emerging trends in the market for rheometry, Professor Billiar and Doctor Cirka would have to license it for less money because there is less need for another application in medical industry.

With regard to competitive forces in the market, the business model canvas for licensing EVR ends up being more attractive. Instead of going up against the industry leaders and established companies, they come to us to compete for EVR. In this situation it gives our business model more leverage in deciding who to license EVR to and what the acceptable value is to its prospects.

In conclusion, the licensing business model canvas appears to be most attractive way to get EVR to market because of its current potential value and its avoidance of competition within an already developed market. For these aforementioned reasons, the licensing conclusion overcomes the disadvantages outlined within this section.

5.1.3 Joint Venture Business Model

While our sponsor does not have a formal entity in place, we speculate that a joint venture would provide greater access to shared resources and distribution networks but all risks would be shared by both partners collectively. Furthermore, the largest constraint on the joint venture business model is being able to find another company that would support the commercialization of EVR. This search could take a long period of time. Based on this disadvantage it would take longer form a joint venture then it would to simply license the patent for EVR.

5.1.4 Holding Business Model

The only constraint that exists on our holding business model canvas is time. Choosing not to sell EVR or selling EVR to the first interested company means the opportunity to leverage our position is be gone. By just holding the patent for EVR, it loses its value over time as similar methods are patented, rheometry technology improves, and the market becomes more crowded.

Conversely, market trends support holding the patent for EVR. By holding, it allows for further discovery of alternative methods and uses for EVR. Holding also lets the medical rheometry market mature allowing us more time to recognize key trends and competing forces. Recognizing different trends helps identify more opportunities to evaluate and explore for EVR.

Holding the patent for EVR until the market matures allows dominant market competitors to become stronger. Stronger competition in the market means that if the patent was to be sold in the future any market share gained would be smaller than it is now. Holding would also give competitors more time to develop their own methods and patents weakening EVR's overall value. This makes the holding business model canvas less attractive because it loses more its value over time.

In conclusion, holding EVR to wait for the market to develop is attractive as long as our sponsor does not wait until too many competitors with similar innovations enter this arena or the value of this innovation becomes stale and outdated.

5.1.5 Abandoning Business Model

Abandoning the patent for EVR would only be advantageous if its value drops significantly on the market, its investment is seen as too risky, or it is not profitable enough. Effectively, abandoning means that the business model for EVR would no longer exist, this subsection is just a theoretical placeholder for this option.

5.2 Discussion of Survey Findings

Unfortunately, we received no responses for the manufacturers' survey and only 2 responses for the users' survey out of the 203 surveys that were sent out. In light of this lack of response, we feel it is necessary to repeat that the responses reported herein represent the opinions of those who replied to our surveys and therefore have only yielded rudimentary suggestions. This minute sample size does not represent enough data to deduce trustworthy recommendations. Thus, the project group had to transitioned to our Product Comparative Study in order to produce tangible results to our sponsor.

5.3 Limitations and Further Research

Our project could open the door to future projects to revisit our methods and adapt them to develop a new plan to continue this research.

One step that we did not effectively investigate was placing phone calls to some of the organizations. We mainly searched for email addresses due to our survey delivery system being an online resource. Yet, if we had searched for phone numbers, we may have found a solid contact and have spoken to that contact directly and/or followed up with. Direct interaction may have motivated people to respond to the survey we had emailed to them.

Data gathered from real-world responses, in written responses or via phone or in-person interviews, would give further credence to our group's recommendations.

Additionally, we could have made question 6 on the User survey much more specific by providing examples or potential multiple choice format options. The open ended format allowed our survey takers to free form their responses without structure. As a result, we did not receive any usable data due to data skew. If we were able to do it again, we would have added options for the respondents and an “other” line in case our options were not applicable to their organization.

6. Interdisciplinary Reflections

This project meets the requirements of a management engineering degree and business degree because it shows our ability to apply business and marketing concepts to commercializing a new patent in an existing market. We were able to research rheometers and develop a methodology for getting Eccentric Viscoelastic Rheometry to market by applying the concepts we learned in previous classes and through research. In our methodology, we used consumer research, questionnaire development, and product comparison studies to get results and make conclusions to we could make qualified recommendations to our sponsor. Additionally, we employed business models that helped our group envision the bigger picture which showed us how external factors can impact a new venture.

This project also meets the requirements of a biomedical engineering concentration because it shows an understanding of the basic concepts taught in biomedical engineering design, instrumentation, and materials. A basic understanding is needed in these areas of biomedical engineering in order to grasp what a rheometer is, how it operates, and what is important when comparing other rheometers and rheological methods on the market.

We were able to mesh the concepts we learned from these disciplines and methods into a cohesive project and the recommendations that we provide to our sponsor also reflect this culmination of learning, market research, and modeling.

7. Recommendations

Based on the survey data, and business model canvases we created for a start-up, licensing, joint venture, holding and abandoning, we recommend holding the patent for EVR. In general, sales and manufacturing of plate on plate systems are infrequent among the companies in our analysis, this points to the decline of plate on plate system for commercial use. Unfortunately, the decline in the use of this type of rheometer commercially means that the growth of this rheology market segment will also slow down. By holding the patent and waiting to see how fast the market segment grows, gives them more time to see where there is the most disposable wealth in the market. Disposable wealth might be the most important factor in this decision long term because it shows which segments are growing the most, which segments people want the most, and which segments they resist and why. Understanding where the disposable wealth accumulates in the market over time helps you make the best decision when deciding to license the patent for EVR. When the time comes to license EVR on the market, depending on the trends and data, it would be acceptable to license the patent anywhere from \$10,000 to \$100,000 (Perkel, 2011). These patent dollar values are based on the minimum and maximum accepted potential values of EVR currently on the market and will likely change over time.

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Appendix A: Survey for Rheometer Manufacturers

What is your email address? __________________________

1. On average, how much does it cost to manufacture your base rheometer model?
2. On average, how much do you sell the model mentioned in the last question for?
3. What features do you believe are most important to your customers?
4. What factors most influence the pricing on this model (Check/circle all that apply)?
    a. Customization
    b. Competition within Marketplace
    c. Market Demand
    d. Features
    e. Manufacturing/production costs
    f. Overhead Costs
    g. Repeat Customer Relationship
    h. Package pricing (i.e. bulk pricing...one customer purchasing more than one unit at a time)
    i. Government Regulations
    j. Other ___________________
5. How do you prospect for new customers looking to purchase rheometers (i.e. do you use a specific medium to do so)?
    a. Email distribution lists
    b. Telemarketing
    c. Mailers
    d. Contacts that use your website
    e. Previous Customers
    f. Media advertising
    g. Social Media
    h. Other _________________
    i. Unknown
6. What demographics do you concentrate your prospecting efforts on?
    a. Universities
    b. Corporations
    c. Unaffiliated Researchers
    d. Other ____________________
7. What technique does your company currently employ in manufacturing one of these devices?
    a. Casting

b. Molding
c. Imaging
d. Machining
e. Forming
f. Joining
g. Other _________________
h. Unknown

8. How are your products typically assembled?
   a. Automated Assembly Line (i.e. no human touch)
   b. By Hand Assembly (i.e. all human touch)
   c. Combination of both
   d. Other ______________________
   e. Unknown

Appendix B: Survey for Rheometer Users

What is your email address? ___________________________

1. In what process does your company currently use a Rheometer device? I.e What do you use it to measure?

2. What materials are being analyzed or measured in this process?

3. Have you come across a sample that was too small or irregular for your current product to analyze?
    a. If yes, how did you proceed in analysis? (i.e. did you stop the analysis? Use a different means of measurement? Or did you contract it out? Etc.)

4. When using your current rheometer, can you foresee any improvements that could be made to the accuracy of its readings?

5. If you were to switch your current product to a new innovative design, what characteristics would you look for in this new product?

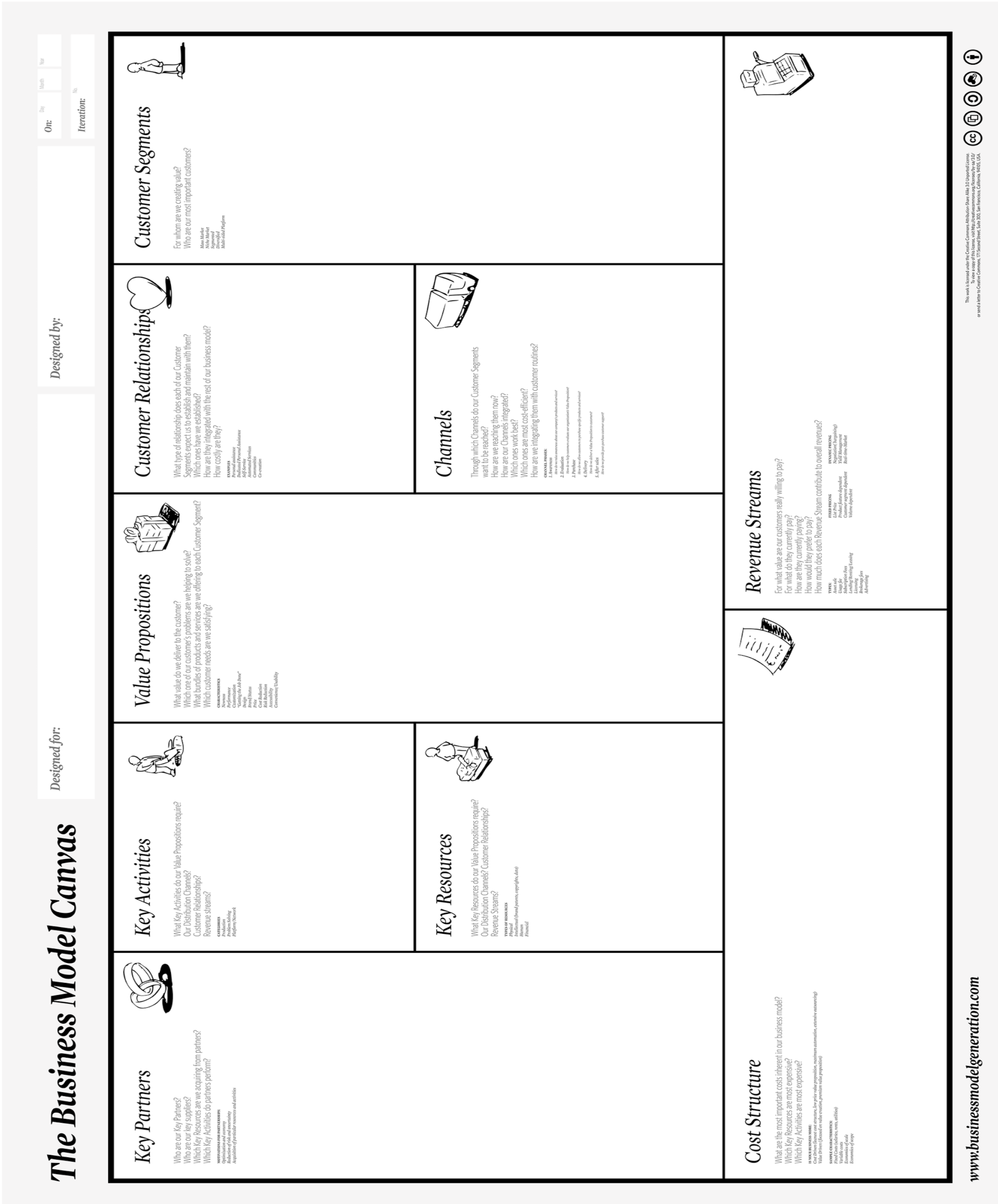
6. Who in your organization would make the decision(s) on whether or not to make a switch of this nature?

7. Of these characteristics, which are most important to your company with your current Rheometer technology?
    a. Cost
    b. Accuracy
    c. Usefulness
    d. Ease of use
    e. Versatility

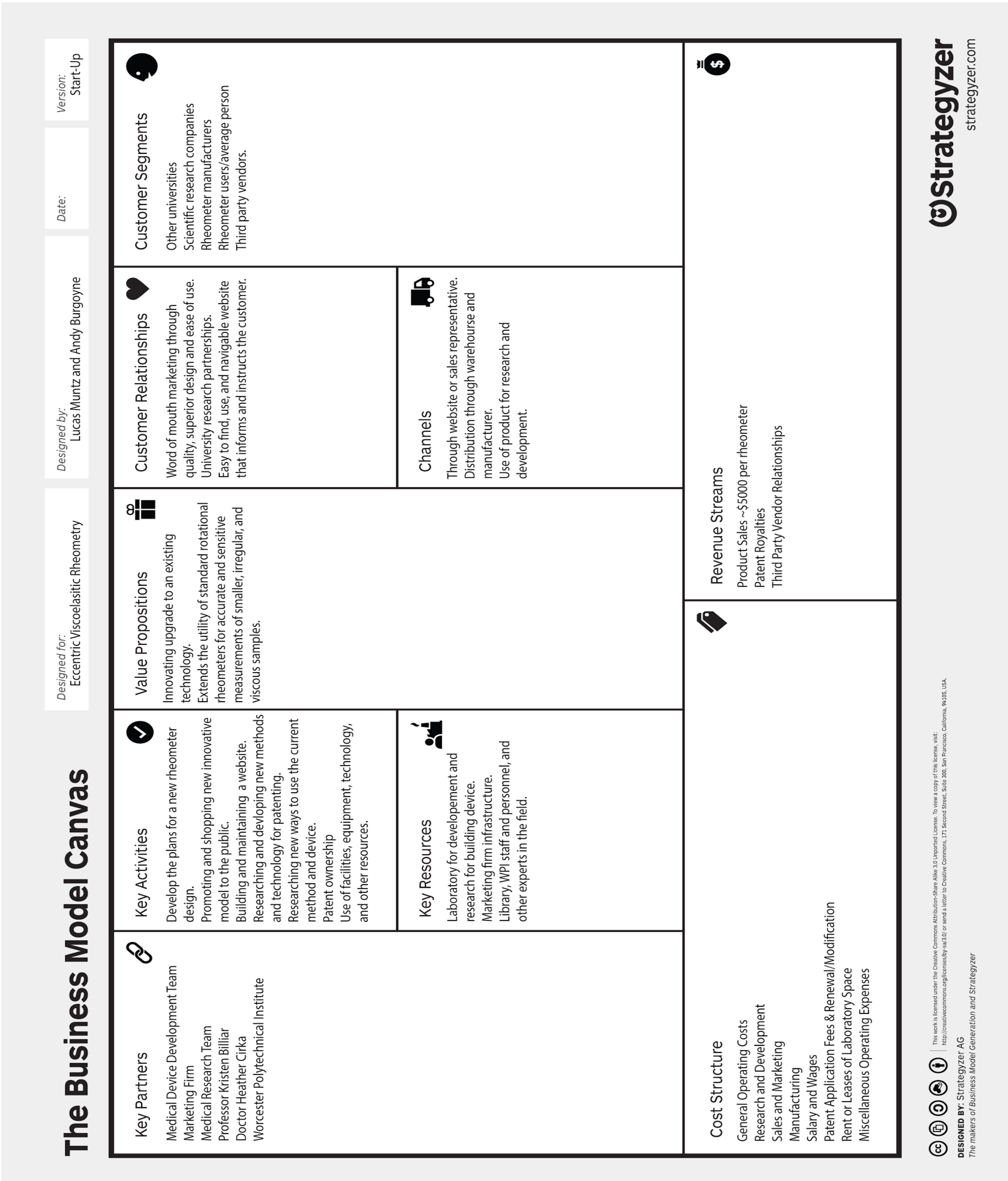
8. If your company was to explore new Rheometer technologies, what would be the number one selling point for you?
    a. Lower Cost
    b. More Accurate Readings
    c. Improved Usefulness
    d. Easier to use than current product
    e. More versatility that current model

9. Who makes the purchasing decisions within your organization?

Appendix C: Business Model Canvas (Strategyzer, Web. & Cowan, Web)



Appendix D: Start-up Business Model Canvas



Appendix E: Licensing Business Model Canvas

The Business Model Canvas

Designed for: Eccentric Viscoelasitic Rheometry

Designed by: Lucas Muntz and Andy Burgoyne

Date:

Version: License

Key Partners

Target Company Purchasing License
Patent expert and rheometer expert
Law Firm
Professor Kristen Billiar
Doctor Heather Cirka
Worcester Polytechnical Institute

Key Activities

Negotiating patent value.
Help inform and determine the value of the patent in the current market.
Litigation
Researching new ways to use the current method and device.
Patent ownership
Use of facilities, equipment, technology, and other resources.

Key Resources

Industry knowledge
Patent databases
Courts
Library, WPI staff and personnel, and other experts in the field.

Value Propositions

Innovating upgrade to an existing technology.
Extends the utility of standard rotational rheometers for accurate and sensitive measurements of smaller, irregular, and viscous samples.

Customer Relationships

Easily communicate superior design and how it will benefit the company by saving them time and making their product more attractive.
Highlight innovations differentation from the usual method.

Channels

Through sales pitche and presentations directly to company or at conventions.

Customer Segments

Rheometer Manufacturers and
Rheometer Distributors

Cost Structure

Consulting Fees
Litigation and Lawyer Expenses
Patent Application Fees & Renewal/Modification
Rent or Leases of Laboratory Space

Revenue Streams

Patent Worth & Royalties

Appendix F: Joint Venture Business Model Canvas

The Business Model Canvas

Designed for: Eccentric Viscoelasitic Rheometry
Designed by: Lucas Muntz and Andy Burgoyne
Date:
Version: Joint Venture

Key Partners
Marketing Firm
Professor Kristen Billiar
Doctor Heather Cirka
Worcester Polytechnical Institute
Venture Capitalist(s)
Consulting Firm

Key Activities
Promoting and shop new innovative model to the public and potential investors.
Researching new ways to use the current method and device.
Patent ownership
Use of WPI facilities, equipment, technology, and other resources.
Supply capital (if needed)
Research and pair other organizations that share the same values, goals, and interests.

Key Resources
Connects to popular advertising sources and businesses.
Laboratory for developement and research for building device.
Marketing firm infrastructure.
Library, WPI staff and personnel, and other experts in the field.
Capital
Utilizing their market knowledge and resources

Value Propositions
Innovating upgrade to an existing technology.
Extends the utility of standard rotational rheometers for accurate and sensitive measurements of smaller, irregular, and viscous samples.

Customer Relationships
Partnership to provide general funding and return on investment.
Building a joint venture together that shares the same goals, values, and interests.

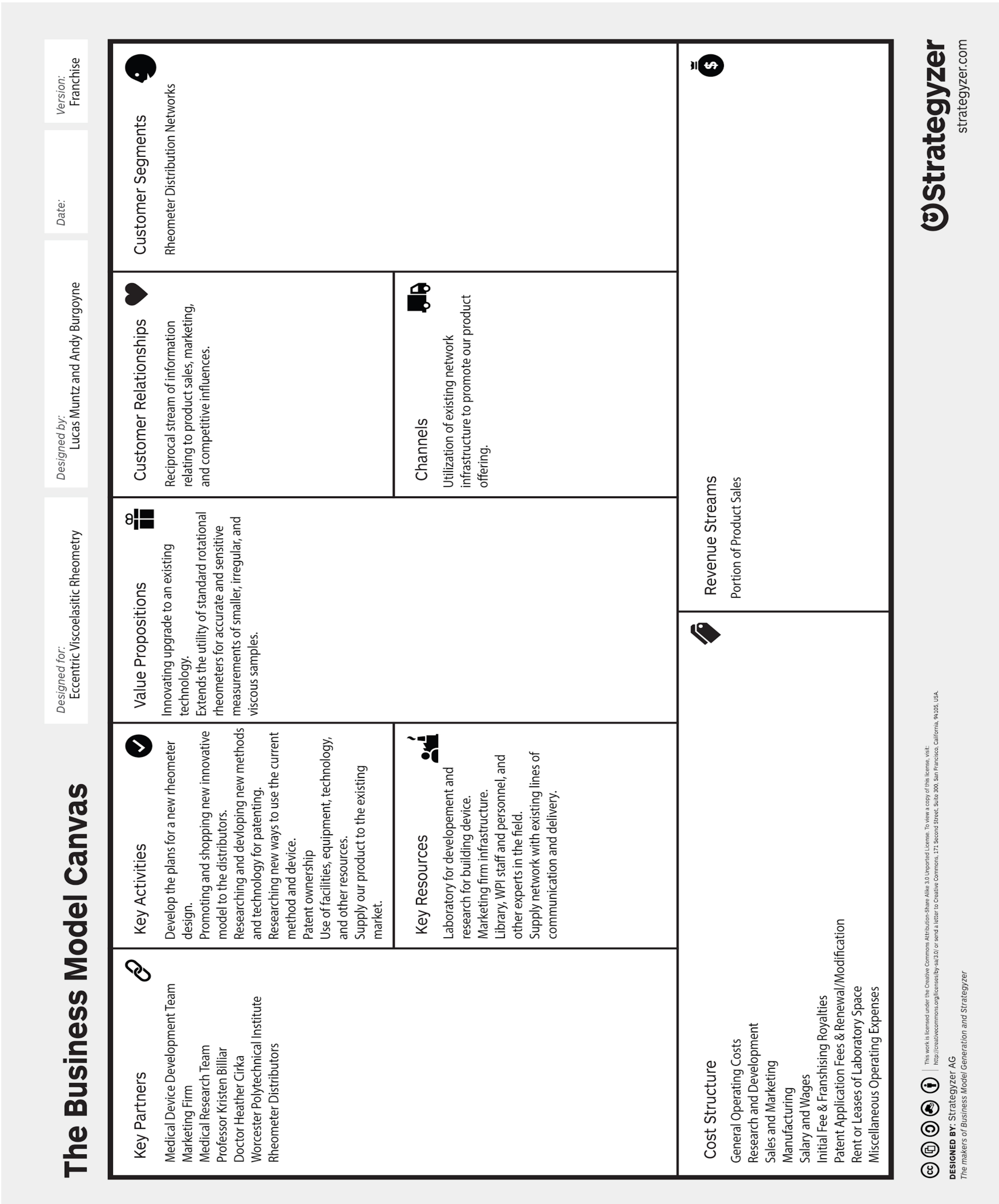
Channels
Through general marketing and consultation (head hunters).
Pitches and presentations for companies and conventions.

Customer Segments
Ventrue Capitalists
Potential Business Partners

Cost Structure
General Operating Costs
Sales and Marketing
Salary and Wages
Patent Application Fees & Renewal/Modification
Rent or Leases of Laboratory Space
Consulting Fees
Dividends on Investors Return
Miscellaneous Operating Expenses

Revenue Streams
Product Sales and Distribution ~$20,000 per rheometer
Additional Partner Revenue
Third Party Vendor Relationships

Appendix G: Franchise Business Model Canvas



The Business Model Canvas

Designed for: Eccentric Viscoelasitic Rheometry
Designed by: Lucas Muntz and Andy Burgoyne
Date:
Version: Franchise

Key Partners
Medical Device Development Team
Marketing Firm
Medical Research Team
Professor Kristen Billiar
Doctor Heather Cirka
Worcester Polytechnical Institute
Rheometer Distributors

Key Activities
Develop the plans for a new rheometer design.
Promoting and shopping new innovative model to the distributors.
Researching and devloping new methods and technology for patenting.
Researching new ways to use the current method and device.
Patent ownership
Use of facilities, equipment, technology, and other resources.
Supply our product to the existing market.

Key Resources
Laboratory for developement and research for building device.
Marketing firm infrastructure.
Library, WPI staff and personnel, and other experts in the field.
Supply network with existing lines of communication and delivery.

Value Propositions
Innovating upgrade to an existing technology.
Extends the utility of standard rotational rheometers for accurate and sensitive measurements of smaller, irregular, and viscous samples.

Customer Relationships
Reciprocal stream of information relating to product sales, marketing, and competitive influences.

Channels
Utilization of existing network infrastructure to promote our product offering.

Customer Segments
Rheometer Distribution Networks

Cost Structure
General Operating Costs
Research and Development
Sales and Marketing
Manufacturing
Salary and Wages
Initial Fee & Franshising Royalties
Patent Application Fees & Renewal/Modification
Rent or Leases of Laboratory Space
Miscellaneous Operating Expenses

Revenue Streams
Portion of Product Sales

Appendix H: Holding Business Model Canvas

The Business Model Canvas

Designed for: Eccentric Viscoelasitic Rheometry
Designed by: Lucas Muntz and Andy Burgoyne
Date:
Version: Holding

Key Partners
Professor Kristen Billiar
Doctor Heather Cirka
Worcester Polytechnical Institute

Key Activities
Researching and devloping new methods and technology for patenting.
Researching new ways to use the current method and device.
Patent ownership
Use of facilities, equipment, technology, and other resources.

Key Resources
Library, WPI staff and personnel, and other experts in the field.

Value Propositions
Innovating upgrade to an existing technology.
Extends the utility of standard rotational rheometers for accurate and sensitive measurements of smaller, irregular, and viscous samples.

Customer Relationships
None

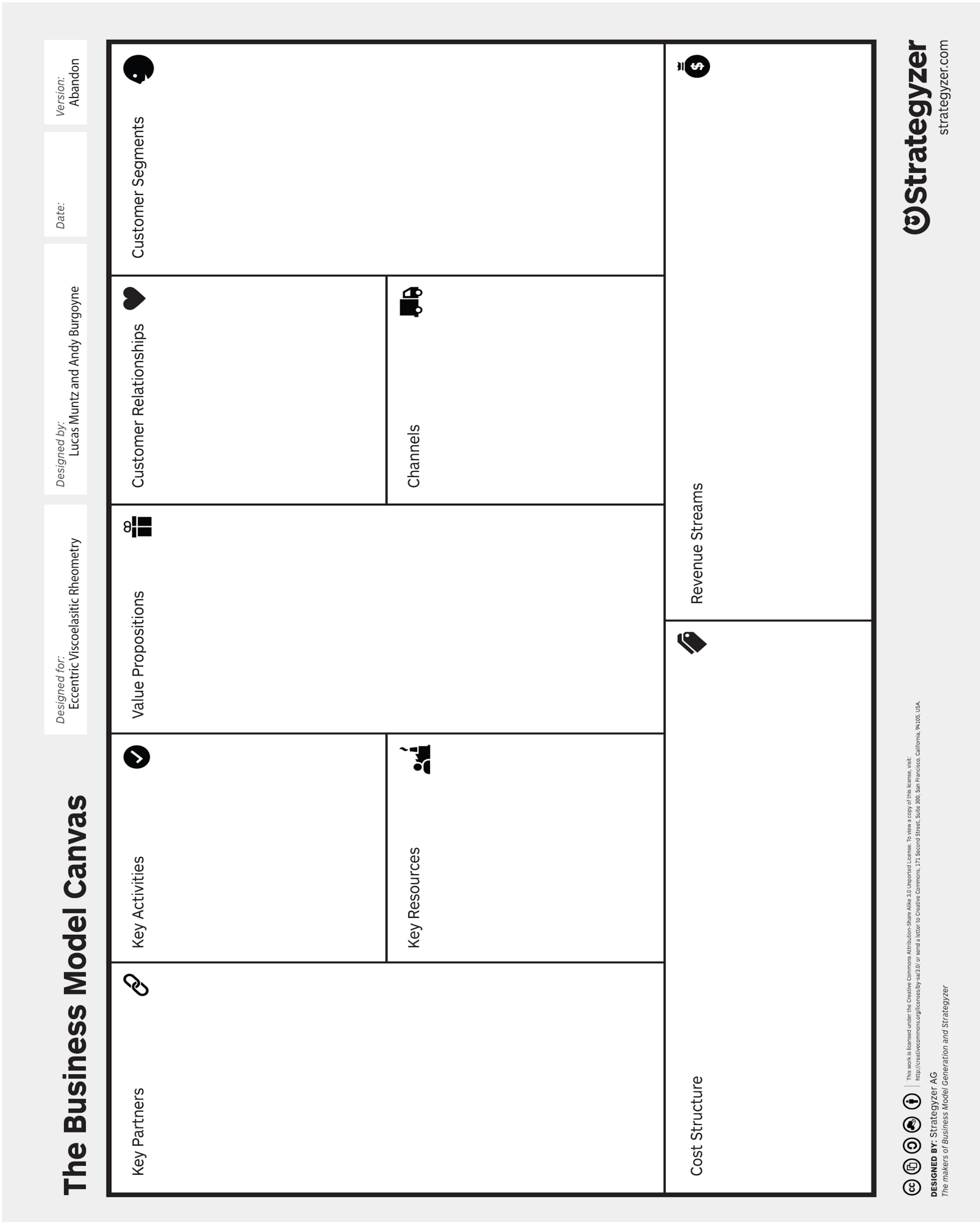
Channels
None

Customer Segments
None

Cost Structure
Patent Application Fees & Renewal/Modification

Revenue Streams
None

Appendix I: Abandoning Business Model Canvas



Appendix J: Market Data for Figure 12: Types of Rotational Rheometers on the Market

Company	# of Models	Dynamice Shear or Hybrid	Rotational Cylinder	C and P,P and P, MDR	Linear Shear	Capillary
Ektron Tek	4	0	0	4	0	0
TA Instruments	7	7	0	0	0	0
Rheometer Services Inc	2	1	0	0	0	1
Brookfield Engineering	5	1	1	1	2	0
Malvern Instruments	3	1	0	1	0	1
Anton-Paar Instruments	7	7	0	0	0	0
C.W. Brabender Instruments, Inc	4	4	0	0	0	0
Thermo Fisher Scientific Inc.	6	5	0	0	0	1
Freeman Technology's FT4	1	0	1	0	0	0
CSIRO Industrial Physics	1	0	0	0	0	1
Sezna Alpha Technologies	5	3	0	1	0	1
ATS Rheosystems	4	1	0	1	2	0
GBC Scientific	1	0	0	1	0	0

A&D Company, Limited	1	0	0	1	0	0
Brabender GmbH & Co. KG	6	0	4	0	1	1
Cooper Research Technology	2	1	0	0	1	0
Dynisco	5	0	0	0	0	5
Gibitre Instruments S.r.l.	2	0	0	2	0	0
Göttfert Werkstoff-Prüfmaschinen	4	0	0	0	0	4
Imatek	1	0	0	0	0	1
Instron	2	0	0	0	0	2
LAMY RHEOLOGY	1	0	0	1	0	0
RIGCHINA GROUP COMPANY	4	0	4	0	0	0
Shimadzu Europa	2	0	0	0	0	2
Stable Micro Systems	4	0	0	0	4	0
Fann Instrument Company	4	0	4	0	0	0
Benz Co., Inc	2	0	0	2	0	0
Qualitest	9	2	3	1	0	3
Dolphin Instruments	5	0	4	1	0	0

Grace Instrument	5	0	5	0	0	0
KROHNE, Inc	1	0	0	0	0	1
Humboldt Mfg. Co.	3	1	1	0	1	0
Rainhart Co.	3	2	0	0	1	0
Canon Instrument Company Inc.	4	1	0	1	2	0
Streamline Automation, LLC	1	0	0	0	0	1
Gomaplast Machinery Co.	4	0	0	4	0	0
Future Digital Scientific Corp Company	4	1	0	2	1	0
GENEQ, Inc	2	1	0	0	1	0
Germann Instruments	1	0	1	0	0	0
Vilastic Scientific, Inc	3	0	0	1	0	2
	135					

Appendix K: Product Data for Figure 13: Types of Rheometers Sold by Company

Company	Model
A&D Company, Limited	RV-10000A
Anton-Paar Instruments	MCR 702 TwinDrive
Anton-Paar Instruments	MCR 102, 302, 502
Anton-Paar Instruments	72 and MCR 92
Anton-Paar Instruments	RheolabQC
Anton-Paar Instruments	SmartPave: Asphalt Rheometer
Anton-Paar Instruments	Furnace Rheometer System FRS 1600
Anton-Paar Instruments	High-Throughput Rheometer: HTR
ATS Rheosystems	CANNON TE-BBR
ATS Rheosystems	CANNON TE-BBR Pro
ATS Rheosystems	CANNON Black Pearl
ATS Rheosystems	ATS Rheosystems StressTech
Benz Co., Inc	ODR ASTM D-2084
Benz Co., Inc	ODR ISO-3417

Brabender GmbH & Co. KG	Extensopgraph-E
Brabender GmbH & Co. KG	Farinograph-TS
Brabender GmbH & Co. KG	Farinograph-AT
Brabender GmbH & Co. KG	Farinograph-E
Brabender GmbH & Co. KG	GlutoPeak
Brabender GmbH & Co. KG	Aqua-Inject
Brookfield Engineering	RST Controlled Stress Rheometer
Brookfield Engineering	RST Soft Solids Tester
Brookfield Engineering	DV3T Rheometer
Brookfield Engineering	PVS Rheometer
Brookfield Engineering	RS Portable Rheometer
C.W. Brabender Instruments, Inc	Intelli-Torque Plasti-Corder Torque Rheometer
C.W. Brabender Instruments, Inc	ATR Plasti-Corder Torque Rheometer
C.W. Brabender Instruments, Inc	ATR Food Torque Rheometer
C.W. Brabender Instruments, Inc	Intelli-Torque Food Rheometer
Canon Instrument Company Inc.	TE-BBR Thermoelectric Bending Beam

Canon Instrument Company Inc.	TE-BBR Pro Thermoelectric Bending Beam
Canon Instrument Company Inc.	Black Pearl Contrtolled Rate Rotational
Canon Instrument Company Inc.	Stresstech HR High Resolution
Cooper Research Technology	Bending Beam Rheometer
Cooper Research Technology	Dynamic Shear Rheometer
CSIRO Industrial Physics	OLR (On-line rheometer)
Dolphin Instruments	DV3T Rheometer
Dolphin Instruments	Rheometer
Dolphin Instruments	Portable Rheometer
Dolphin Instruments	RST-CPS Touch Rheometer
Dolphin Instruments	CC Touch TM Rheometer
Dynisco	ViscoSensor Online Rheometer
Dynisco	ViscoIndicator Online Rheometer
Dynisco	Capillary Rheometer (LCR 7000 Series)
Dynisco	Continuous Melt Rheometer (CMR IV)
Dynisco	Flow Characterization Rheometer (FCR-R)

Ektron Tek	EKT-2003SA
Ektron Tek	EKT-2003S
Ektron Tek	EKT-2003SP
Ektron Tek	EKT-2003RPA
Ektron Tek	EKT-100H
Fann Instrument Company	RheoVADR Rheometer
Fann Instrument Company	IX77 Rheometer
Fann Instrument Company	Rheometer Model 280 Hand-Powered
Fann Instrument Company	Rheometer Model 50SL
Freeman Technology's FT5	FT4 Powder Rheometer
Future Digital Scientific Corp Company	SVT20
Future Digital Scientific Corp Company	ODG
Future Digital Scientific Corp Company	OCA50
Future Digital Scientific Corp Company	DCAT LBE
GBC Scientific	MFR 2100
GENEQ, Inc	Sharp-BBR

GENEQ, Inc	Bohlin Rheometer DSR II
Germann Instruments	ICAR Rheometer
Gibitre Instruments S.r.l.	Rheocheck Profile Moving Die
Gibitre Instruments S.r.l.	Rheocheck Profile Oscillating Disk
Gomaplast Machinery Co.	Monsanto Rheometer R100
Gomaplast Machinery Co.	TechPro ODR Rheotech Rheometer
Gomaplast Machinery Co.	Rheometer R-100
Gomaplast Machinery Co.	Monsanto Rheometer
Göttfert Werkstoff-Prüfmaschinen	Rheograph 20
Göttfert Werkstoff-Prüfmaschinen	Rheograph 25/50/75/120
Göttfert Werkstoff-Prüfmaschinen	PVT 500
Göttfert Werkstoff-Prüfmaschinen	Contifeed
Grace Instrument	M5600 HPHT Rheometer
Grace Instrument	M7500 Ultra HPHT Rheometer
Grace Instrument	M7500 HPHT Cement Rheometer
Grace Instrument	M7800 Ultra HPHT Rheometer

Grace Instrument	M9200 HPHT Foam Rheometer
Humboldt Mfg. Co.	Bending Beam Rheometer
Humboldt Mfg. Co.	Rotational Viscometer and Rheometer
Humboldt Mfg. Co.	Dynamic Shear Rheometer
Imatek	R6000
Instron	SR20
Instron	SR50
KROHNE, Inc	Viscoline Inline Process Rheometer
LAMY RHEOLOGY	RM 200 Touch CP 4000
Malvern Instruments	Kinexus Range
Malvern Instruments	DSR
Malvern Instruments	Rosand Range
Qualitest	MDR-3000
Qualitest	Concrete Rheometer BT2
Qualitest	Viskomat XL
Qualitest	Viskomat NT

Qualitest	QT-M3000F
Qualitest	QT-M3000FA
Qualitest	CR-6000 Capillary Rheometer
Qualitest	LCR 7000 Twin Bore Capillary Rheometer
Qualitest	SLIPER
Rainhart Co.	Bending Beam Rheometer
Rainhart Co.	BDSR-II-I Bohlin Instruments DSR(Air)
Rainhart Co.	BDSR-II-I Bohlin Instruments DSR(Mechanical)
Rheometer Services Inc	rs5000 Series
Rheometer Services Inc	R6000 Capillary Rheometer
RIGCHINA GROUP COMPANY	Model RC-35
RIGCHINA GROUP COMPANY	Automated Digital Rheometer, 6 Speeds
RIGCHINA GROUP COMPANY	Automated Digital Rheometer, 12 Speeds
RIGCHINA GROUP COMPANY	NRC-130
Sezna Alpha Technologies	ODR 2000
Sezna Alpha Technologies	MDR 2000

Sezna Alpha Technologies	PMDR 2000
Sezna Alpha Technologies	Pioneer MDR
Sezna Alpha Technologies	ARC 2020
Shimadzu Europa	CFT-500D
Shimadzu Europa	CFT-100D
Stable Micro Systems	TA.XT.plus Texture Analyzer
Stable Micro Systems	TA.XT.plus 100 Texture Analyzer
Stable Micro Systems	TA.HD.plus Texture Analyzer
Stable Micro Systems	TA.XT.Express Texture Analyzer
Streamline Automation, LLC	High Shear Rate Capillary Rheometer
TA Instruments	ARES-G2
TA Instruments	Discovery HR-1
TA Instruments	Discovery HR-2
TA Instruments	Discovery HR-3
TA Instruments	RSA-G2 Solids Analyzer
TA Instruments	Q800 DMA

TA Instruments	Rubber Rheometers
Thermo Fisher Scientific Inc.	HAAKE MARS Rheometer
Thermo Fisher Scientific Inc.	HAAKE Viscotester iQ Rheometers
Thermo Fisher Scientific Inc.	HAAKE PCR Process Control Rheometer
Thermo Fisher Scientific Inc.	HAAKE Rheostress 1 Rheometer
Thermo Fisher Scientific Inc.	HAAKE RotoVisco 1 Rotational Rheometer
Thermo Fisher Scientific Inc.	HAAKE CaBER 1 Capillary Breakup Extensional Rheometer
Vilastic Scientific, Inc	V-E System
Vilastic Scientific, Inc	BioProfiler
Vilastic Scientific, Inc	Vilastic-3

Appendix L: Market Data for Figure 14: Rheometer Applications by Material (Sourced from Brookfield Engineering)

Material	Laboratory	Process	Texture	Powder
Adhesives	3	0	0	0
Asphalt	1	0	0	0
Beverages	3	0	0	0
Chemicals	4	0	0	0
Cleaners	1	0	0	0
Foods	15	2	11	4
Glue	0	1	0	0
Oil and Gas	2	3	0	0
Paints, Inks, Coatings	4	1	0	0
Paper Coatings	0	1	0	0
Personal Care/Cosmetics	9	0	0	0
Petroleum Products	1	0	0	0
Pharmaceuticals/Medical	2	0	0	0
Slurries	0	2	0	0